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On a Collection of Raised Beach Fossils from Spitsbergen.

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I. INTRODUCTION.

LARGE collections of material have been brought back by numerous Arctic Expeditions, and, as many writers have pointed out, much of this raised beach material proves changes of climatic and other ecological conditions during Quaternary times. Before correlation of Quaternary deposits in Spitsbergen and other Arctic lands can become at all certain, it is essential that as many detailed contributions as possible should be made to our total collection of facts.

Very little stratigraphical work has been done upon the Quaternary deposits of Spitsbergen, partly owing to the greater attention which has been paid to the coal-bearing deposits of that country, and partly to the difficulty of finding and working out Recent sections. Such deposits are usually covered with coarse alluvial matter brought down by torrents caused by the melting of the snow in spring, or by screes; furthermore, the ground in most places is frozen, even in summer, below a depth of 2 or 3 feet (0·6 to 1 m.), which holds up excavation. It is only occasionally that one is able to find good exposures, and since several were encountered during the Oxford University Expeditions to Spitsbergen in 1921, 1923, and 1924, it was thought desirable to record the observations that were made, although these are not sufficiently extensive to form the basis of any wide conclusions. It is only by the accumulation of details from a great many parts of Spitsbergen that the data necessary for a general correlation can be obtained.

The districts in Spitsbergen from which fossiliferous material was obtained during these expeditions can be classified conveniently under four headings, which will be described separately :—

Klaas Billen Bay, Ice Fjord.
Prince Charles Foreland.
Wijde Bay.
Hinlopen Strait.

The greater part of the material from these places was found in raised beaches, or in associated deposits, but there is also a small collection of mollusca which were dredged from the existing sea-bottom near one of the raised beach localities, at Klaas Billen Bay, and a description of these Recent shells will be included here for comparison with the raised beach forms. Both of these collections, which have been deposited in the Oxford University Museum, were made by Mr. C. S. Elton, while Mr. D. Baden-Powell was responsible for systematic work on them, particularly for naming the varieties. For the specific identification of some part of the mollusca we must express our thanks to Mr. C. G. Robson and to Mr. J. R. le B. Tomlin ; we are also indebted to the following specialists for their kind assistance : Professor E. J. Garwood for naming the calcareous algae ; Mr. Heron Allen for undertaking to identify the Foraminifera ; Mr. T. H. Withers for advice concerning the Cirripedes ; Mr. John Walton for identifying specimens of a marine alga. We must also record our thanks to Professor A. M. Carr-Saunders, who suggested and helped to carry out the dredgings undertaken in 1921, and to Mr. R. W. Segnit who helped to work out the details of the section at Klaas Billen Bay.

II. ANALYSIS OF RECENT FAUNA.

By way of comparison with the raised beach shells to be described, we will first give a list of molluscs belonging to species which occur at the present day in the fjord near Bruce City, Klaas Billen Bay. These were dredged in 1921 with the assistance of Professor A. M. Carr-Saunders, the depth of water being 5 or 6 fathoms (10 to 12 m.).

Chlamys islandica (Muller).

Two living, very young, probably referable to this species. Length about 20 mm.

Musculus discors (Linne) var. *laevigata* Gray.

Large number living, greatest length being 25 mm. This comparatively small size confirms an observation by Jensen (1912) [1] to the effect that size of shell in this variety diminishes when traced to colder waters; for instance, the maximum sizes at the following places were approximately :—

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[1] The titles of works by former writers on the subjects discussed here will be found in the list of references at the end of the present paper.

Jan Mayen	28 mm.
Greenland	41 mm. (average).
Iceland	48 mm.

There is also confirmation of this diminution in size by Grieg (1924), who reported a maximum of 19·5 mm. from Novaya Zemlya.

Astarte borealis Chemnitz var. *placenta* Morch.

Five adults measured, but young also present. Length/height ratio of the adults varied between 75 and 83 per cent, averaging 78·6 per cent.

Astarte montagui Dillwyn var. *warhami* Hancock.

Four adults whose length/height ratio averages 77·0 per cent, and only one measures over 80 per cent. This one individual is perhaps nearer var. *striata* Leach.

Astarte elliptica Brown, var. *depressa* Posselt.

Out of eleven adults measured, only three give a greater value than 74 per cent for the length/height ratio, the rest belonging to this cold variety. The great majority of the Astartes measured were fresh.

It will be as well to explain that the method employed by Jensen (1912) is followed here, and that the figures given by Grieg (1924) for shells from Novaya Zemlya are also in complete agreement. Jensen's method, especially for *Astarte*, is to measure the height of the shell as a percentage of the length. This percentage is found to bear an approximate relation to the climate in which the shell lives, and also, though in an arbitrary way, to the chief varietal distinctions. For instance, he indicates the following ways in which *Astarte* may be used :—

Variety.	*Percentage.*	*Distribution.*
Astarte borealis Chemnitz.		
Typical	Over 80	Warm tendency.
var. *placenta*	Under 80	Cold tendency.
Astarte montagui Dillwyn.		
var. *warhami*	76 to 80	Cold.
Striata	80 to 90	Intermediate.
Typical	90 to 96	Warm.
Astarte elliptica Brown.		
var. *depressa*	Under 74	Cold.
Typical	74 to 84	Intermediate.
var. *crassa*	Over 84	?

The evidence in the case of *A. elliptica* is not so definite as with the other two species, as there is, according to Jensen, a race living in West Greenland giving figures of 84 to 85 per cent. It can be seen, however, that the shells living at Klaas Billen Bay show almost without exception the measurements which should be expected from a comparison with the work of Jensen and Grieg.

Mya arenaria Linne.

Two individuals in the Klaas Billen dredgings, one of which was empty, measure :—

Long. 33 mm., lat. 15 mm., perc. 45·3.
Long. 25 mm., lat. 15 mm., perc. 60·0.

Mya truncata Linne.

Five individuals, three being represented by single valves, were measured, and they are specially important, as they show no tendency towards var. *uddevallensis* Hancock, as might have been expected. Grieg (1924, p. 11) also notes that this form was not found by him in Novaya Zemlya. The Klaas Billen shells measured :—

Long. mm.	Lat. mm.	Percentage.
33	24	78·7
31	23	74·2
27	21	77·7
30	20	66·6
23	15	65·2

Two important points are to be noted in connection with *Mya truncata.* Firstly, that the more truncate form goes with a cold climate, whereas this is not necessarily true of the less truncate form : This species is used by Brøgger as follows :—

Typical.	Under 90 per cent.	Usually warm.
var. *uddevallensis.*	Over 90.	Cold.

Secondly, it is also important to notice that the percentage is often approximately a function of the size of the shell, and in fact the very young of *M. truncata* are often almost indistinguishable from the young of *arenaria*, suggesting that the latter is the older of the two forms phylogenetically.

Saxicava arctica (Linne).

Two small individuals, evidently young. In length/height ratio, they vary between 50 and 54·5 per cent.

Pandora glacialis Leach.

One fresh individual, at Klaas Billen Bay. This shell differs from *P. inaequivalvis* (Linne) in having a more truncate and less pointed posterior margin than *inaequivalvis*, though perhaps it should only be a variety of that species. Jeffreys described it (1865, *British Conchology*, iii, p. 25) as var. *obtusa.* The present shell has been compared with a number of normal examples of " inaequivalvis " from Studland, Dorset, but no measurements have yet been made ; the shape of the posterior margin, however, appears fairly constant.

Thracia truncata Brown.

Two empty valves belonging to an individual measured :—

Long. 21 mm., lat. 16 mm., percentage 76.

The length/height ratio of an individual mentioned by Grieg (1924, p. 22) is 75·8, so that the Klaas Billen shell is not unlike those of Novaya Zemlya, although more examples should be measured before we can draw any conclusions from these figures.

Chiton sp.

Some individuals, possibly referable to *Tonicella marmorea* (Fabricius) are among the Klaas Billen dredgings.

Margarites helicina (Fabricius).

After *Astarte borealis, Margarites* is about the most common genus in the material.

Margarites grønlandica (Chemnitz).

Present in about equal numbers with *M. helicina*. Both species are in a fresh state.

Natica affinis Gmelin.

One empty shell, which is only 11·5 mm. long, a more usual length for this species being 18 mm. It is therefore perhaps rather young.

Boreotrophon truncatus (Strom.).

One shell containing the animal, but having the outer lip broken, though not badly enough to prevent the counting of 20 ribs on the body-whorl.

Buccinum glaciale Linne.

Two adults, one empty, belong to this species, and it is noticeable that the empty shell is more water-worn than the other.

Buccinum grønlandicum Chemnitz.

Much more common than *B. glaciale,* all fresh, of small size, and thin-shelled.

On the whole, the molluscan association which has been described from Klaas Billen Bay is Arctic in character, but not intensely so, a modification which might be expected in the " warmer " part of Spitsbergen waters. It bears a striking resemblance to the collection made by Grieg in the Mishigin Fjord, Novaya Zemlya. It is not considered necessary to publish illustrations here either of the living or of the fossil forms, as no new species are being described, and all the species and varieties mentioned are well known to specialists.

III. LOCALITIES STUDIED.

We will now describe the exact conditions under which the raised beach fossils were found in each of the four areas mentioned above : Klaas Billen Bay, Prince Charles Foreland, Wijde Bay, and

Hinlopen Strait. For maps showing the places mentioned in the present paper, the reader is referred to Summerhayes and Elton (1928, pp. 193 and 201).

Klaas Billen Bay, Ice Fjord. Fossiliferous material from this area was found at four points :—

(*a*) Bore No. 1 Section.

(*b*) The bed of a stream at (*a*), and apparently washed out of that section.

(*c*) " Pecten Section."

(*d*) Upper Raised Beaches.

(*a*) *Bore No.* 1 *Section.*—A section through the upper part of a 40 feet raised beach was exposed in a gully below a cairn near one of the Scottish Spitsbergen Syndicate borings, known as " Bore No. 1 ", which is situated one quarter of a mile south-west of Bruce City, and was studied in 1921 with the assistance of Mr. R. W. Segnit. The height of the bed of the stream at this point is 30 feet above sea-level, as shown on the S.S.S. map made by Mathieson in 1919. The top of the raised beach section is several feet below the cairn mentioned above. For sketch-maps showing the distribution of the raised beaches in the neighbourhood of Bruce City the reader is referred to a paper by Mr. Summerhayes and Mr. Elton (1928, p. 103). The beds found in Bore No. 1 Section were :—

	Ft.	in.
8. Shingle	3 to 4	0
7. Fine white sand, with one small gasteropod (specimen lost)	1	0
6. Blue sandy clay, unfossiliferous		7
5. Stiff black clay with marine shells, including *Mytilus*, but no algae		1½
4. Thin clay band, unfossiliferous		8
3. Thin band with abundant plant remains, including *Desmarestia*		¼
2. Black sandy clay, unfossiliferous, with persistent lignite band at base		⅜
1. Stiff black clay with large and small rounded pebbles and abundant marine shells and calcareous algae	4	0
Base of section frozen.		

A detailed description of the marine animals in this section will be found in Part IV of the present paper. At the moment it is sufficient to indicate the conditions under which the fossiliferous beds were laid down. The climatic equivalent of the foraminifera and mollusca found in Bed 5 is, without exception, Finmark or the Murman Coast, and they represent a depth of water of not more than 1 or 2 fathoms (2 to 4 m.). Bed 3 includes *Desmarestia aculeata* (Linne) Lamour. This form, according to Mr. John Walton (1922) is still living in the fjord at a depth of 3 or 4 fathoms (6 to 8 m.) in the Laminaria Zone, and occurs also in other parts of Spitsbergen. No marine animal remains were found at this horizon. *Mytilus edulis* and *Littorina littorea*, both of which were found in

Bed 5, no longer live in Spitsbergen. In Bed 1 the calcareous alga *Lithothamnium glaciale* Kjell has been identified by Dr. Garwood. This still lives in the fjord, and was dredged by us from a depth of 5 or 6 fathoms (10 to 12 m.). The marine fauna from this bed also included serpulids on a stone and young *Mytilus edulis*. The higher part of the section appears to represent deposition in shallower, the lower part in deeper, water, and the evidence of the mollusca of the various beds strongly supports that supplied by the plants with regard to the depth of deposition. The presence of Mytilus shows that Bed 1 is warm as well as Bed 5. Bones of a large whale were found lying on top of the raised beach material.

(*b*) " *Stream Section.*"—In the bed of the stream at this same locality, and apparently washed out of Bore No. 1 Section, were found marine shells including *Mytilus edulis* and *Littorina rudis*, both of which forms are now extinct in Klaas Billen Bay. Again, the climatic equivalent of the association as a whole is Northern Norway.

(*c*) " *Pecten Section.*"—A very short distance away to the south there is another section, actually in one of the small tributary valleys on the left bank of the stream, and it is referred to as the " Pecten Section " owing to the local abundance of *Chlamys islandicus*. The fauna is not unlike that of Bore No. 1 Section, but no distinctly warm shells are present, and if the two correspond, the Pecten Section agrees most closely with the lowest bed only of Bore No. 1 Section.

(*d*) *Upper Raised Beaches.*—In this vicinity shells were also found at an estimated height of between 100 and 150 feet (30 to 45 m.). Among the shells from this level, *Cyprina islandica, Mytilus edulis, Littorina littorea*, and a particular form of *Astarte montagui* unite in demonstrating that they lived at a time when the climate was more genial than at present, and it is interesting to compare this high-level warm fauna with that found at the head of Wahlenberg Bay, as described by K. S. Sandford (1929, p. 547).

Prince Charles Foreland.

Shells were collected from Prince Charles Foreland on a raised beach which is situated on the north-east coast of the island between Heemskirke Ness and Point Carmichael. Its height above mean sea-level is about 40 feet (12 m.). As far as can be seen from the few shells from this raised beach, the climatic equivalent of those shells labelled A 16 is somewhat cold, as proved by the *uddevallensis* tendency in *Mya truncata*, whilst that of the shells labelled A 32 has a warm tendency, as shown by the form of *Astarte borealis*, although no shells such as *Mytilus* were found.

Wijde Bay Area.

Marine shells were found in this area both at Aldert Dirkses Bay and Salmon Lake on the east side of the fjord, and at Fork Valley on the west side.

(*a*) *Aldert Dirkses Bay.*—The chief section studied in this area is situated immediately south of Aldert Dirkses Bay. This section extends from about 2 or 3 feet (about 1 m.) above the present drift-line on the sea-shore to a height of about 20 feet (6 m.). The beds found here were :—

		Ft.	in.
6.	Large and small boulders	10	0
5.	Sand, with marine shells, including *Mytilus* . .		2
4.	Fine shingle, with no shells	1 ft. to 1	2
3.	Marine bed with *Mytilus*, the most common shell being *Macoma calcarea*		3
2.	Marine bed with cold fauna		1
1.	Sand with foraminifera and marine mollusca, especially *Mya* in situ. The matrix and fauna is so similar throughout this bed, that its various layers were probably contemporaneous		10
	Base frozen.		

As far as the mollusca in Bed 5 can be interpreted, they point to the " warm " type of conditions. The same is also true of Bed 3, which has a sandy matrix containing foraminifera and echinoid spines. The association of *Macoma calcarea* with *Mytilus edulis* shows accurately that the fauna is Norwegian rather than Arctic, and one of the Foraminifera, *Truncatulina refulgens* also strongly confirms this value for climatic equivalent. The mollusca and foraminifera from Bed 2 point to rather colder conditions, but an insufficient number of forms were found at this horizon to be certain on this point. In Bed 1 there was found an association of *Truncatulina refulgens* with a " warm " form of *Astarte montagui* and *Turtonia minuta*, unmistakably pointing to some part of Norway as the climatic equivalent of this horizon. Again, the presence of a *Lepeta*, and the absence of *Littorina* or *Mytilus*, and the nature of the foraminifera, all suggest that Bed No. 1 was deposited in about 10 fathoms (18 m.). It would appear that the lower part of this section was deposited in the deeper water than the upper part, and comparison in this respect between this section at Aldert Dirkses Bay and that already described at Klaas Billen Bay is most interesting.

Since the transportation of mollusca by birds occurs in the Arctic, for instance, *Buccinum* by Eider Duck, this fact must be considered ; but there is no evidence of this affecting the observations in question. The Myas in Bed No. 1 of the Aldert Dirkses Bay Section are considered to be in place of growth, because of their depth below the surface of the sand in this deposit, and also because the siphuncle is preserved in a number of examples.

(*b*) *Salmon Lake.*—In a raised beach at a height of between 50 and 70 feet (18 to 22 m.) above the sea a few mollusca were found, also *Balanus balanus* Linne. The mollusca represent a cold climate. On the shores of the same lake a few more mollusca occurred, which do not appear to belong to such a cold type as those found higher up, but they may have been washed down from the higher deposit.

(*c*) *Aldert Dirkses Bay.*—At sea-level, a few raised beach shells were found under soil-creep, and these, especially an *Astarte*, appear to represent a " warm " tendency in climate.

(*d*) *Fork Valley.*—Raised beach shells were also found at this one locality on the western shore of Wijde Bay, at a distance of about 2 miles up from the sea, and at a height of about 250 feet (75 m.). These shells were collected by Dr. T. G. Longstaffe, and are particularly interesting, owing to the great height at which they were found. Unfortunately nothing very definite can be said about the climatic equivalent of the fauna, neither typically warm nor typically cold forms having been seen. At the same place a large log was found embedded in the ground, which was almost certainly driftwood at some former period.

Hinlopen Strait Area.

Fossiliferous material was found at three places in this area :—

(*a*) Lomme Bay.
(*b*) Duym Point.
(*c*) Gylden Island, at the mouth of Wahlenberg Bay.

(*a*) *Lomme Bay.*—On the west shore of this fjord, two valves of *Chlamys islandicus* were found on a raised beach at a point over 50 ft. above the sea (15 m.). It is not possible to estimate the climatic equivalent of these shells, although owing to their large size they do not appear to have a specially warm tendency, though they may be of Norwegian type.

(*b*) *Duym Point.*—An interesting association was found here, and foraminifera were extracted from the clay matrix of the shells, but were, unfortunately, too worn for identification. The mollusca, which were at a height of some 50 to 70 feet (18 to 22 m.), include a thin-shelled (warm) form of *Saxicava,* and again *Chlamys islandicus,* one valve having *Balanus balanus* Linne in position of growth. Some of the shells were found near sea-level, but were apparently washed down from above.

(*c*) *Gylden Islands.*—Shells apparently belonging to raised beach material were brought from the larger of these two islands, having been found mostly in boulder clay at heights of 75 feet (22 m.), 83 feet (12 m.), 28 feet (9 m.), and 16 feet (5 m.) above the sea. No great climatic distinctions can be observed between the shells from these four heights, though there is a general warm tendency throughout. No such distinctive forms as *Mytilus* were, however, found. Since these shells were found at these levels in stone polygons, they cannot strictly be said to be in place. The great difference in levels, however, suggests that raised beaches of more than one age are represented.

IV. ANALYSIS OF RAISED BEACH FOSSILS.

It is most interesting and instructive to compare the Quaternary fossils which were brought back by the Oxford Expeditions with the living plant and animal population of Spitsbergen. It is well known that several species found in Arctic raised beaches no longer inhabit those parts of the world, and mention has already been made in the present paper of several forms of this kind, as, for instance, *Mytilus edulis*, certain *Littorinae*, *Cyprina islandica*, and *Turtonia minuta*, and among the foraminifera *Truncatulina refulgens*, which, according to the Reports of the Challenger Expedition, no longer lives north of the Faeroes. The term " climatic equivalent " is used in the present paper in connection with raised beach fossils to denote the present latitude or habitat of the fossil plant or animal community, and serves as a means of expressing changes in the climatic or other conditions since the time at which the raised beach deposits were laid down.

In Part III of this paper all that is necessary has been said about the plants and barnacles from the Spitsbergen raised beaches; further, the echinoid spines found in the matrix at one or two places were too water-worn for identification, therefore only the foraminifera and the mollusca remain to be dealt with in this analysis.

Foraminifera.

Those shells in this list which are not assigned to any particular bed were found in Aldert Dirkses Bay Section, Bed No. 1, and the majority of the species are from this deposit.

Miliolina seminulum (Linne). Bed 5, Bore No. 1 Section, three individuals. Aldert Dirkses Bay Section. One test in Bed 2, and frequent in Bed 1.

Miliolina oblonga (Montagu). One test.

Miliolina subrotunda (Montagu). One test.

Miliolina sp. One worn shell.

Ammodiscus gordialis Jones and Parker. One test in Aldert Dirkses Bay Section, Bed 3.

Haplophragmium canariense (d'Orbigny). One shell.

Cassidulina crassa d'Orbigny. In Bed No. 1, one shell also a variety occurs rarely.

Cassidulina laevigata d'Orbigny. Frequent.

Polymorphina communis d'Orbigny. One shell.

Polymorphina lactea Walker and Jacob, var. *oblonga* Will. One shell in Bed No. 1.

Truncatulina lobatula (Walker and Jacob). Very common, in Bed No. 1.

Truncatulina variabilis (d'Orbigny). Very rare.

Truncatulina refulgens (Montfort). In the Aldert Dirkses Bay Section, three individuals were found in Bed 3, and it was very common in Bed 1. This species is important, as it does not now inhabit the Arctic.

Truncatulina akneriana (d'Orbigny). Common.

Pulvinulina karsteni (Reuss). Rare.

Nonionina depressula (Walker and Jacob). In the Aldert Dirkses Bay Section, two individuals from Bed 3, and frequent in Bed 1.

Nonionina orbicularis Brady. Frequent.

Nonionina umbilicatula (Montagu). Rare.

Nonionina pompilioides (Fichtel and Moll). One shell in Bed 3 of the Aldert Dirkses Bay Section, and one shell in Bed 1 of doubtful identity, but probably this species.

Nonionina scapha (Fichtel and Moll). Common.

Nonionina stelligera d'Orbigny. One shell.

Polystomella arctica Parker and Jones. One individual in Bed 5, Bore No. 1 Section. From the Aldert Dirkses Bay Section, four shells in Bed 3, one in Bed 2, and very common in Bed 1.

Polystomella striato-punctata (Fichtel and Moll). Aldert Dirkses Bay Section; two in Bed 3, and very common and very variable in Bed 1.

Orbulina universa d'Orbigny. One spherical object in Bed 1, about the right size for this species, but either water-worn or covered over with lime.

Mollusca.

Mytilus edulis Linne. Bore No. 1 Section, Bed 5. Several adult individuals, valves not united, also one small individual in Bed 1. One individual from the stream at this place. None of these shells are either broken or water-worn, and therefore they are unlikely to be derived from elsewhere. One valve was found in the "Upper Raised Beaches" near Klaas Billen Bay, at a height of 100 feet or more.

Aldert Dirkses Bay Section. In Beds 5 and 3, but not in Bed 1.

At the present day *Mytilus* only inhabits the tidal zone at places which are free of sea-ice, and its present limit of distribution in the Barents Sea barely reaches the warmest parts of Novaya Zemlya. Its occurrence as a raised beach fossil in Spitsbergen not only proves its original much wider distribution, but suggests that the conditions of the formation of sea-ice were also different from those of the present day. The shells from Klaas Billen Bay and Aldert Dirkses Bay are no isolated examples, as it has been found fossil in other parts of Spitsbergen, for example, the head of Wahlenberg Bay (K. S. Sandford, 1929, p. 547), Coles Bay, Icefjord (Gripp, 1925, p. 37), Green Bay (presumably Green Harbour); also reported by Dr. Gripp, Advent Bay (C. W. Blomstrand, 1864, and Loven in Oswald Heer, 1870); Rendalen, Saurie Hook, Icefjord (Loven in Heer, 1870); and Treurenberg Bay (von Yhlen, 1865). Nor is the fossil distribution of *Mytilus* restricted to Spitsbergen, as it has also been found in Franz Joseph Land on the one side (Fridtjof Nansen, 1902, p. 420), but also in Greenland on the other (see references in A. S. Jensen, 1909). It is not proposed to attempt here to give a complete list of references to climatic optimum (or optima) in the Arctic, but the widespread nature of the phenomenon denies explanation by change in the direction of the wind, and the most likely cause has been the general raising of the temperature of these northern seas by some other agency.

Chlamys islandicus Chemnitz.—Bore No. 1 Section. Small forms only, both in Beds 5 and 1; up to 20 mm. in length, whereas 50 mm. is a more usual size. Jensen (Reports of the Ingolf Expedition) considers that individuals living in the sheltered parts of a fjord are small, especially near the southern limit of their distribution (at present near Bergen). Also small in the "Pecten Section" at Klaas Billen Bay, where they attain a length of 34·5 mm.

Lomme Bay and Duym Point. Shells from here were large, being 62 mm. long in the former raised beach, and 107 in the latter.

Gylden Islands. Only fragments were brought back from here. Glacial striae were not found on these fragments, though looked for carefully.

It appears that the degree of shelter may have influenced the rate of growth of these shells, but many more examples should be measured before generalizing on this point.

Crenella decussata (Montagu).—Bed 1 of Bore No. 1 Section. As most of the forms in this bed, either dwarfed or young.

Turtonia minuta (Fabricius).—Bed 1 of Aldert Dirkses Bay Section. Both individuals and separate valves found whilst washing this sand for foraminifera. Although this species was originally discovered in Greenland waters, it is doubtful whether it has ever been found living in such cold waters as Wijde Bay, and it was not found in the dredged material from Klaas Billen Bay.

Serripes grønlandicus (Chemnitz).—Broken valves were obtained in Bed 5, Bore No. 1 Section, and in the material from Prince Charles Foreland, but in no case were the shells in a good enough state of preservation for any measurements: even the specific identification of these shell-fragments is none too certain.

Astarte borealis (Chemnitz).—Bore No. 1 Section. Beds No. 5 and 3. Mostly young or dwarfed, but one valve in Bed No. 5 measured—

Long. 18·5 mm. Lat. 17·2 mm. Ratio 92·9 per cent.

By comparison with Part II of the present paper it can be seen that this shell shows no tendency whatever towards var. *placenta*, and is most typically warm.

"Stream Section" at Klaas Billen Bay. Both young and adult present, and although the former have not been measured, they do not appear to belong to a specially cold type.

"Pecten Section" at Klaas Billen Bay. One valve :—

Long. 16·7 mm. Lat. 14·6 mm. Ratio 87·4 per cent.

"Upper Raised Beaches." Several valves, not typically cold.

Prince Charles Foreland. Rather worn about the umbonal area, but measured as accurately as possible :—

Long. 38·7 mm. Lat. 33·2 mm. Ratio 85·8 per cent.
,, 40·0 ,, ,, 32·7 ,, ,, 81·8 ,, ,,

It can be seen that these shells have a warm tendency.

Section at Aldert Dirkses Bay. Individuals and separate valves, on being measured, were found to have a ratio of between 82 and 86, thus having a warm tendency. This was true of Beds 3 and 1, but Astarte was not found in Bed 2.

Duym Point. Two right valves and one left valve were found, but they were too worn about the umbonal region to be measured.

Gylden Islands. Separate valves which do not belong to individuals, had a ratio of about 82 per cent.

It must be pointed out that all these raised beach shells differ distinctly and persistently from the examples of *Astarte borealis* which were found in the dredgings, and the fossil shells can all be assigned to *forma typica* rather than to var. *placenta* Morch. Whether this fact is of phylogenetic, or of mere climatic, significance cannot be discussed here, but it must be emphasized that in publishing lists of raised beach shells it is often as important to state their varietal tendencies as to name them specifically, and it is a great pity that this has not been done more frequently in the past.

Astarte montagui Dillwyn.—The difference between the fossil and dredged shells which may be assigned to this species is as striking as in the case of *Astarte borealis.*

From the "Upper Raised Beach" at Klaas Billen Bay, valves of *montagui* type were taken, one of which measured :—

Long. 11·8 mm. Lat. 33 mm. Ratio 90·8 per cent.

Shells from Bed 1, Aldert Dirkses Bay Section measured :—

Long. 24 mm. Lat. 29 mm. Ratio 82·7 per cent.
,, 24 ,, ,, 27 ,, ,, 88·8.

The strong tendency towards the "warm" extreme of var. *striata*, and even to *forma typica* itself, is exhibited by all the adults present. When the sands from the Bore No. 1 and Klaas Billen Bay Sections were being sorted for foraminifera, a large number of young Astartes were found, but it was not easy in every case to decide whether they belonged to the *borealis* or to the *montagui* group. This point can sometimes be decided by an examination of the hinge-plate, and some of the young which were measured gave values for the length/height ratio of 94 to 99 per cent, and they could in fact be seen without measurement to be distinctly rounded and globular. It would seem, therefore, that the "warm" form of both these two species is the most primitive, and perhaps var. *globosa* Møller is the most primitive form of *Astarte montagui* Dillwyn.

Astarte elliptica Brown.—One valve at a height of 75 feet (22 m.) on Gylden Island. The shell measured :—

Long. 28 mm. Lat. 22 mm. Ratio 78·6 per cent.

Although it would be unsafe to attach too much importance to the measurement of a single shell, it can be seen that this fossil is at least as warm as any that were found in the dredgings, which belong to this species.

Cyprina islandica Linne.—This species was only found at one locality as a fossil, the " Upper Raised Beach " at Klaas Billen Bay, being represented by fragments including hinge-plates. This species is now extinct in Spitsbergen, but has been found previously as a raised beach fossil at Advent Bay (Loven in Oswald Heer, 1870), and also by Loven at Saurie Hook (1870). The height above the sea at Advent Bay was 10 to 20 feet (3 to 6 m.).

Thyasira flexuosa Montagu.—Bore No. 1 Section, Bed 1. Eighteen valves were found in the sand, some of which may belong to individuals, though now separate. The largest measured :—

Long. 6 mm. Lat. 5·9 mm. Ratio 98·3 per cent.

The largest of these valves are twice the size of those described by Grieg from Novaya Zemlya (1924, p. 10), but the significance of variation in this species is not yet as well known as in *Astarte*.

Aldert Dirkses Bay Section, Bed 1. One individual of an obscure opaque luciniform shell which may be referable to this species. It is possible that its transparency has been destroyed by mineralization.

Macona calcarea Chemnitz.—Bore No. 1 Section. In both Beds 5 and 1, large numbers of valves, many belonging to individuals, but never actually united.

Also in the " Stream Section ", " Pecten Section ", and in the " Upper Raised Beach ", this species was found.

It was also brought back from Beds 3 and 1 of the Aldert Dirkses Bay Section, but not from Bed 5. Again, valves often belonged to individuals, but were no longer united.

Among all this material, it was found possible to make measurement of more than sixty shells, and the length/height ratio was found to vary between 69 and 80 per cent, although any figure below 72 per cent was quite exceptional, and only a few were over 78. Among the measurements given by Grieg (1924, p. 10) for shells from Novaya Zemlya, calculation for length/height ratio gives results varying between 70 and 74 per cent, his largest measuring only 15 mm. On the other hand, Brøgger mentions and figures a " var. *maxima* " from the Yoldia Clay of the Oslø District, which attains a size of 52 mm. (Brøgger, 1900, p. 22), but this variety was not found in the collections from Spitsbergen, as the largest was 34 mm. among the raised beach shells ; it would also seem that none of the Spitsbergen shells correspond with Brøgger's *langagtig form* (rather elongated), as described by him (1900, p. 126).

It is important to find out whether any change in the physical form of *Macoma* can be found which corresponds to the colder or warmer parts of its range, as with some of the species of *Astarte*, and as the examples given by Greig and by Brøgger are not numerous enough to prove this point one way or the other, an attempt has been made to measure examples of *Macoma calcarea* from a Scottish deposit of known climatic equivalent. The deposit in question was a clay found above the banks of the Kinness Burn, St. Andrews, Fife, in which *Macoma calcarea* is associated with *Scrobicularia plana*, and therefore the climatic equivalent of this deposit is known to be the neighbourhood of Bergen. Unfortunately only one valve of *Macoma* has so far been found, which measures :—

Long. 21·8 mm. Lat. 16·7 mm. Ratio 76·6 per cent.

As the shells from the Spitsbergen raised beaches, from Novaya Zemlya, and from the Kinness Burn Clay differ from each other in no particular respect, we are forced to the conclusion that *Macoma calcarea* does not vary with climate ; possibly, however, a larger number of measurements on Recent shells would prove this to be otherwise.

Mya arenaria Linne.—Bore No. 1 Section. Both young and adult present, length/height ratio up to 68·8 per cent.

Aldert Dirkses Bay Section, Bed 3. One left valve which measured :—

Long. 25·2 mm. Lat. 15·4 mm. Ratio 61·1 per cent.

Among the valves of *Mya truncata* which were found on Prince Charles Foreland, one which is 60 mm. large is almost as near *arenaria* in shape as it is to *truncata*. After a long consideration of a number of examples, it seems that there is great variation in the shape of the posterior margin, and also in both the shape of the hinge-plate and in the curvature of the pallial line. It is considered quite possible that there is much intermediate variation between the two forms, *arenaria* and *truncata*, and it is suggested that a length/height ratio of 70 per cent might be made an arbitrary line of division between the two species, although there appear to be exceptions. For instance, the *truncata* with strong *arenaria* tendency from Prince Charles Foreland has a ratio of 75 per cent, whilst a left valve of *truncata* from Duym Point has a ratio of 66·6 per cent. In the main, however, the great majority of *arenaria*-forms have a ratio of under 70 per cent, whereas most *truncata*-forms have a ratio of 70 per cent and over. It is doubtful whether *Mya arenaria* has previously been found as a raised beach fossil in Spitsbergen.

Mya truncata Linne.—Bore No. 1 Section. Very common in Bed 5, but apparently not found in Bed 1. Length/height ratio up to 77·6 per cent, and therefore no tendency towards var. *uddevallensis* Hancock. As explained in Part II of the present paper, this variety is here used in the sense of shells of *truncata* whose length/height ratio is 90 per cent or over. This is also approximately the sense in which Brøgger used the varietal name.

" Stream Section." One valve, ratio 83·9 per cent. Also normal forms in the " Pecten Section ".

Upper Raised Beaches. Three valves measured :—

Long.	26·2	mm.	Lat.	17·4	mm.	Ratio	66·4	per cent.
,,	47·3	,,	,,	36·2	,,	,,	76·4	,, ,,
,,	42·8	,,	,,	34·8	,,	,,	81·3	,, ,,

These figures are quoted here to show that the evidence of *Mya* corroborates that of *Mytilus* in showing that the climate of this beach was warm.

Prince Charles Foreland. Of the four valves found here, one which has already been mentioned as having some of the characteristics of *arenaria* measured :—

Long. 60 mm. Lat. 45 mm. Ratio 75 per cent.

The other three valves have a length/height ratio of between 80 and 83.

Aldert Dirkses Bay Section. Bed 5. A large number, with truncation up to 77·6 per cent. In Bed 3 only fragments were found; in Bed 2 one right valve with a ratio of 68·2 per cent, the cold nature of this bed being indicated by lack of warm forms rather than by the presence of specially cold ones ; Bed 1, no special tendency towards var. *uddevallensis.*

Salmon Lake, Aldert Dirkses Bay. In the raised beach at a height of 50 to 70 feet above the sea (18 to 22 m.), two valves were found which measured :—

Long. 47 mm. Lat. 37 mm. Ratio 81·4 per cent.
,, 46 ,, ,, 41 ,, ,, 89·1 ,, ,,

Both these approach var. *uddevallensis* Hancock, and of all the shells of *truncata* measured during the present investigations these are most typically cold in type. According to Brøgger (1900, p. 230), such forms are now found living only off the coast of Northern Norway, and are restricted to the counties of Tromsø and Finmark; it should, however, be pointed out that this variety can be found in this same area with *Mytilus edulis* and *Littorina littorea,* since the northern part of the distribution of these two molluscs overlaps the southern portion of the distribution of this variety of *Mya,* and it is therefore not correct to assign a high arctic climate to a Quaternary deposit, because such forms as var. *uddevallensis* have been found in it.

On the shores of the same lake, and under soil-creep at sea-level at the same place, valves were found of normal type.

At the interesting locality Fork Valley, a fragment of one valve of *Mya truncata* was found. Enough of the shell was preserved to show that it does not belong to a very truncate form. At both Duym Point and on Gylden Island (at a height of 38 feet), shells of normal form were found, except the one left valve already mentioned, which measured :—

Long. 66 mm. Lat. 44 mm. Ratio 66·6 per cent.

A consideration of the measurements of *Mya truncata,* both as a fossil and as a Recent shell, which have been given in the present paper, leads us to the conclusion that this species does not vary in shape with climate in the sense that appears to be true of *Astarte.* It is true that the more truncate forms of *M. truncata* are sub-arctic only, and when found associated with other specially cold forms may be Arctic, but the less truncate forms may be either Arctic or Temperate.

Saxicava arctica Linne.—There are three main forms of *Saxicava* found in Arctic raised beaches : *arctica*, *pholadis*, and *uddevallensis*. The first two were described by Linne, and the last by Brøgger (?). It is unfortunate that the name *uddevallensis* has been given to the most truncate of these *saxicava* varieties, and it must not be confused with the variety of *Mya* bearing that name. The difference in shape between these three forms has been well illustrated by Brøgger (1900), *pholadis* on Tab. VII, 8*a* and *b*, *arctica* on p. 342, fig. 32*a*, and *uddevallensis* in fig. 32*b*, and these differences are great enough without having to resort to measurements of length and breadth for the recognition of these main types, in spite of the fact that almost innumerable numbers of intermediate forms occur. It may be added, however, that measurements of length and breadth are not entirely without significance, and a certain variation of length/breadth ratio with climate was found to be constant for Novaya Zemlya shells by Grieg (1924, p. 12), which may be summarized thus :—

pholadis.	Ratio 44 to 54.	Warm tendency.
arctica.	,, 50 upwards.	Cold tendency.

(*uddevallensis*, which according to Brøgger also has a cold tendency, usually about 90 per cent.)

There also appears to be a tendency for *pholadis* to have a thicker shell as it approaches the colder limit of its distribution, though this condition must also sometimes be governed by the supply of lime. From Brøgger's work, and from the present investigation, it is evident that the distributions of *pholadis* and *arctica* overlap to a certain extent. *Saxicava* was found at almost all the localities investigated in Spitsbergen :—

Bore No. 1 Section, Bed 5. *Pholadis* very common, not very thick-shelled, and with no tendency towards *arctica* or *uddevallensis*. In Bed 1, both *pholadis* and *arctica*, both small in size.

" Stream Section." Both *pholadis* and *arctica*, and both thick-shelled. These two also associated in the " Pecten Section ".

Upper Raised Beaches at Klaas Billen Bay. Only *pholadis* found, shell of medium thickness, and the shells typically long, i.e. warm tendency. For instance :—

Long. 30·5 mm. Lat. 13·6 mm. Ratio 45·6 per cent.

Aldert Dirkses Bay Section, Bed 2. *Pholadis*, but thick-shelled. This genus was not found at the other horizons in this section.

Salmon Lake. Both *pholadis* and *arctica*, several of the shells being intermediate between these two.

Fork Valley. Two valves of *arctica*.

Duym Point. *Pholadis*, both thick- and thin-shelled.

Gylden Island. At 28 feet above the sea, again a mixture of thick- and thin-shelled *pholadis*. But at the 16 feet level, normal *pholadis* were associated with *uddevallensis*, suggesting that some of these shells have been derived from higher levels. This was the only locality at which *uddevallensis* was found during the present investigations.

As regards our previous knowledge of the distribution of these shells in Spitsbergen as raised beach fossils, mention in most lists is made only of *arctica*, but the form *pholadis* is specified by Soot-Ryen (1925, p. 6) as fossil at four Spitsbergen localities, Russe-elven, Sassen Bay, Richards Lagoon, and Congress Valley.

Thracia truncata Brown.—Aldert Dirkses Bay Section, Bed 1, was the only deposit in which this species was found fossil during the Oxford Expeditions. A few of the valves belong to individuals, but were not united. The length/breadth ratio varied between 71 and 79, and averaged at about 75. All the shells were rather small, only one measuring as much as 20 mm. by 15 mm. Measurements were made of young shells as well as adult, and these also averaged about 75 per cent in ratio, so that it would seem that in this respect the young do not differ greatly from the adult.

As regards the climate represented by these shells, the length/breadth ratio of the individual dredged at Klaas Billen Bay and an individual from Novaya Zemlya mentioned by Grieg (1924, p. 12) approximates to the mean figure of 75, so that on the measurements so far made we cannot find evidence of variation with climate. The southern limit of true *truncata* appears to be approximately at the Lofoten Islands, and to the south of these its place appears to be taken by the form *villosiuscula* Macgillivray. There may be intermediate variation between these two forms, although the beaks are distinctly more central in *truncata* than in *villosiuscula*.

Lepeta caeca (Muller).—One individual was found in Bed 1, Aldert Dirkses Bay Section. This species has been reported from the raised beach at Coles Bay by Gripp (1925). On the whole, the individual from Aldert Dirkses Bay is smaller than Recent forms from the Arctic, for instance from Davis Straits (Expedition of H.M.S. *Valorous*), and from a position south of Spitsbergen, as reported by Soot-Ryen (1925, p. 6). The mouth of the raised beach shell from Aldert Dirkses Bay measured 9 mm. by 7 mm.

Puncturella noachina (Linne).—Klaas Billen Bay Section, Bed 1. Two individuals ; also two individuals from the stream at the same place. These four shells have been compared with examples in the Barlee Collection at Oxford, and appear to differ from the British form in having a rather longer slit. It is possible, therefore, that the Klaas Billen shells belong to a sub-arctic variety of *noachina*. On the other hand, Gwyn Jeffreys (*British Conchology*, iii, p. 258) considered the slit to be a criterion of individual age. But it must also be noted that the two shells from the Klaas Billen Bay Section also differ from British examples in having their beaks marginal rather than central.

Margarites grønlandica Chemnitz.—Klaas Billen Bay, Bed 1.

A large number of individuals, showing great variation, especially in the intensity of the spiral ribbing. Also four individuals from the stream, and one individual and a fragment from the " Pecten Section ".

Aldert Dirkses Bay Section, Bed 2. One broken individual and other fragments. It is not surprising that these small thin shells are frequently found in a damaged condition ; the fragments were angular and not water-worn, and we are not therefore justified in suggesting that they have been derived from any distance.

Littorina saxatilis (Olivi) ; (*L. rudis* (Maton)).—" Stream Section," Klaas Billen Bay. One individual. From this locality there are also two small ill-preserved gasteropods which have rather the appearance of *Littorina littorea*, but the appearance of the inner lip is so obscure, that they might almost be a species of *Lacuna*.

L. saxatilis is now extinct as living animal in Spitsbergen waters, and therefore represents a period during the Quaternary when the temperature of the sea was higher than it is now. This species has previously been reported by Dr. Gripp (1925) as a raised beach fossil from the west shore of Coles Bay, Icefjord, under the name of *L. rudis* (but it is apparently not as common as a raised beach fossil in Spitsbergen as *L. littorea*), also at Green Harbour by Dr. Gripp.

Littorina littorea Linne.—Bore No. 1 Section, Bed 5. One rather water-worn fragment. " Upper Raised Beaches," Klaas Billen Bay. Of typical form, though rather small in size. This species again provides excellent evidence of the former milder conditions in Spitsbergen, as it no longer lives on shores where shore-ice is formed. It has been found in the raised beach at Advent Bay by Lovel (1870, reported by Oswald Heer).

Buccinum glaciale Linne.—One shell was picked up on Gylden Island, but its appearance is very Recent, what little matrix there is being very earthy. It is doubtful whether this individual is a raised beach fossil ; it may have been carried by Eider Duck.

Trophon clathratus (Linne).—One individual in the stream at Klaas Billen Bay, with less than 14 ribs on the body-whorl.

Gwyn Jeffreys (*British Conchology*, iv, p. 321) considered that a true *clathratus* has only 14 ribs on the body-whorl, whereas the form *truncatus* has about 20 ribs. The two forms also appear to differ in the shape of the mouth, but it has been suggested by Gwyn Jeffreys that there are intermediate varieties, such as *scalaris* Jeffreys, which are only known to range as far south as the Shetlands as living animals. One shell found (empty) in a " warm " part of Novaya Zemlya by Grieg (1924, p. 16) had as many as 26 ribs on the body-whorl, and he appears to disagree with Jeffreys about the distinctions between *clathratus* and *truncatus*.

V. CONCLUSIONS.

It has already been stated at the beginning of this paper that it is our opinion that our knowledge of the Quaternary deposits of

Spitsbergen is at present too fragmentary to allow any correlation over wide areas. One fact is clear, however, that at some time past a more genial climate than the present Arctic conditions has affected these parts of the world. This fact has been recorded by many past investigators, and receives strong confirmation in this present work. Whether this amelioration of climate occurred at more than one period, or whether it can be correlated with climatic optima elsewhere, it is not safe to say until futher work has been done.

In two sections investigated by the Oxford Spitsbergen Expeditions, namely, that at Bore Section No. 1 at Klaas Billen Bay and that at Aldert Dirkses Bay, there is at least a suggestion of contemporaneous uplift during the deposition of the material, which apparently corresponds in time with a genial period, and in the case of Klaas Billen Bay there is some evidence that this uplift has continued into comparatively recent times. As far as these raised beach sections are concerned, however, it is not safe to draw too general conclusions until more sections of a similar nature have been reported.

TABULAR LIST OF MOLLUSCA.

	Bore No. 1 Sections.	Upper Raised Beaches.	Prince Charles Foreland.	Aldert Dirkses Bay.	Salmon Lake.	Fork Valley.	Lomme Bay.	Duym Point.	Gylden Island.
Mytilus edulis . .	×	×	–	×	–	–	–	–	–
Chlamys islandicus .	×	–	–	–	–	–	×	×	×
Crenella decussata .	×	–	–	–	–	–	–	–	–
Turtonia minuta .	–	–	–	×	–	–	–	–	–
Serripes grønlandicum	×	–	×	–	–	–	–	–	–
Astarte borealis . .	×	×	×	×	–	–	–	×	×
Astarte montagui .	–	×	–	–	–	–	–	–	–
var. *striata* .	–	–	–	×	–	–	–	–	–
Astarte elliptica .	–	–	–	–	–	–	–	–	×
Cyprina islandica .	–	×	–	–	–	–	–	–	–
Thyasira flexuosa .	×	–	–	?	–	–	–	–	–
Macoma calcarea .	×	×	–	×	–	–	–	–	–
Mya arenaria . .	×	–	–	×	–	–	–	–	–
Mya truncata . .	×	×	×	×	×	×	–	×	×
Saxicava arctica .	×	–	–	–	×	×	–	–	–
var. *pholadis* .	×	×	–	×	×	–	–	×	×
var. *uddevallensis*	–	–	–	–	–	–	–	–	×
Thracia truncata .	–	–	–	×	–	–	–	–	–
Lepeta caeca . .	–	–	–	×	–	–	–	–	–
Puncturella noachina .	×	–	–	–	–	–	–	–	–
Margarites grønlandica	×	–	–	×	–	–	–	–	–
Littorina saxatilis .	×	×	–	–	–	–	–	–	–
Littorina littorea .	×	×	–	–	–	–	–	–	–
Boreotrophon truncatum	×	–	–	–	–	–	–	–	–

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The Red Crag of Walton-on-the-Naze.

By Percy Fry Kendall.

THE excursion to East Anglia in the week preceding the Centenary Meeting of the British Association will include visits to four of the sections of the Waltonian[1] Red Crag at present accessible, and the occasion seems appropriate for the publication of studies which were interrupted in the year 1885 by my removal to Lancashire and were not resumed until the year 1930, after a lapse of forty-five years.

I find myself in the position of almost the sole survivor of the Crag geologists to whom I owed my initiation, including Edward Charlesworth (who, in 1835, established the succession of the Pliocenes of East Anglia upon which we still rely), Gwyn Jeffreys, Searles V. Wood, jun., R. B. Newton, E. T. Newton, the Rev. H. Canham, W. H. Flower, the three brothers Bell, Harmer, Huxley, Horace B. Woodward, Robert Etheridge, and many others.

The communication which follows was intended to appear in the joint names of Robert George Bell and myself, but his death at the early age of 54 deprived me of a valued friend and Pliocene geology a most trustworthy and discriminating worker. Robert Bell was the eldest of three brothers, all of whom were devoted to some branch of Tertiary palaeontology—Robert was the conchologist,

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[1] I adopt the name "Waltonian" for this sub-division of the Red Crag not only in deference to the general usage, but also because Robert Bell, in a communication to the Geological Magazine, 1887, 554, only six weeks before his death, proposed a classification of the Red Crag into three main divisions—Waltonian, Suttonian, and Butleyan. Harmer apparently overlooked this paper. I agree that "Newbournian" is to be preferred to "Suttonian": there are few English counties that do not boast a Sutton.

George the student of polyzoa, and the versatile Alfred took the rest of the animal kingdom as his province. The lists which accompany this contribution are, unless otherwise stated, so far as the mollusca are concerned, on the authority of Robert Bell, the foraminifera were determined by E. Halkyard, and the corals, polyzoa, echinoderms, crustacea, and vertebrates mainly by myself.

Other authorities are the monographs of the Palaeontographical Society by Searles V. Wood, Harmer, Darwin, Busk, Forbes, Edwards and Haime, Jones and Sherborne, and Jones, Parker and Brady. The first list of species from Walton was, I believe, that by Searles V. Wood,[1] in which he enumerated 118 species of mollusca, then followed Prestwich [2] with 124 ; and A. and R. Bell [3] with 170 sp. The list appended to the memoir on *The Geology of the Eastern End of Essex* (*Walton, Naze and Harwich*) in 1877 gives 181 mollusca, but as two species appear by repetition the net number is 179.

In 1882 in the course of an investigation on behalf of the *soi-disant* Prince of Mantua, continuing *de die in diem* for three months, I was enabled by the use of sieves and by other methods to enlarge the molluscan suite to 287 species.

The other orders were not overlooked, and large additions were made to foraminifera, corals, echinoderms, polyzoa, crustacea, fishes, etc. Wherever practicable a distinction was drawn between the fauna of the lower and the higher divisions, i.e. between that of the uppermost (Artemis) bed and the beds below, and some discrimination, though by no means complete, between the fossils of the minor sub-divisions. In this investigation the truth of the saying was realized : “ You can look for only one thing at a time.” On this principle it was found that a fine sieve, forceps, and a chip-box would suffice for a whole day's close application to one of the thinner beds.

Robert Bell wrote in 1887,[4] a few weeks before his death, “ Very little is actually known of the fossil forms of many of the lower classes of organisms ; indeed, excepting in the Mollusca, the information that has been published is extremely meagre, our knowledge of the Annelids, Echinoderms, Polyzoa, and many other groups of the Invertebrata in which the Pliocenes are very rich, is in fact astonishingly behind that which has been attained as regards Mollusks and Vertebrates.”

This default is to some extent remedied by the Memoir on the Pliocene Rocks of Britain by Clement Reid, who records 197 spp. of molluscs, 50 polyzoa, 7 barnacles, 1 ostracod, 3 annelids, 12 echinoderms (of which three are regarded by Professor Gregory as of only varietal value), 5 corals, and 20 foraminifera. No vertebrata are mentioned.

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[1] *Proc. Geol. Soc.*, xxi, 1866, 538.

[2] *Q.J.G.S.*, xxvii, 1871–2.

[3] *Proc. Geol. Assoc.*, ii, 1873, 185. Read 4th April, 1871.

[4] GEOL. MAG., Dec. III, Vol. IV, 1887, p. 554.

STRATIGRAPHICAL.

The Crag at Walton-on-the-Naze is disposed in four principal hollows in the London Clay which take a nearly east to west course. The deepest of these hollows is opposite Walton tower, where the base of the Crag rests on the London Clay at an altitude of about 60 feet above Ordnance Datum.

In 1883 Robert Etheridge allowed me to transcribe from his notebook the sketches and other information observed by him in the year 1863, exactly twenty years before the time when my examination of the cliffs was made, and I am thus enabled to determine the true form of the Crag sea-bottom at Walton, the sea having in the meantime carried away an additional slice of the land.[1]

The opinion that the hollows were troughs, rather than basins, was formed before I had seen Etheridge's notes, and the comparison with mine shows clearly the disposition of the beds. These earlier sketches indicate three hollows filled with Crag which clearly correspond to the three southernmost of those shown in my section, the most northerly being then no doubt overgrown by vegetation, as it was in 1883; in fact, the correspondence of his section with mine at the northern end, bearing in mind the small amount of waste of the cliff there, justifies the belief that not more than a yard or two, even if that, is the maximum difference between the two versions. Where the London Clay is not overlain by Crag, denudation of the upper cliff is almost negligible and the London Clay forms a steep face to the beach.

Etheridge's notes indicate a maximum thickness of the Crag opposite the Tower of 15 ft. 6 in., which agrees with my measurement to within a few inches; they also indicate that fossils are most abundant at this point.

It will be convenient to describe the exposure at this place as it existed in 1883, and to use it for the purpose of an index.

1	Made earth and gravel	8·2
2	Warp of Searles V. Wood, jun.	–·–
3	Red sand	·8
4	Alternating thin bands of variegated sands and clays . .	3·2
5	Coarse light grey sand with occasional oblique bands of reddish sand. Carbonaceous fragments	1·10
6	Red sand with occasional patches of comminuted shells dipping slightly to north-east	1·8
7	Red shell-bed (the *Artemis Bed*)	2·2
8	Yellow-grey false-bedded sand	1·0
9	Red and yellow sand with a small patch of *Pectunculi* and occasional ironstone nodules. The *Amphidetus* (or *Echinocardium*) *Bed*	2·10
10	A layer of *Pectunculi* and *Mactra arcuata*.	

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[1] When I visited Searles V. Wood, jun., in September, 1884, a few weeks before his death, he drew in my notebook a section of the Walton cliff with an enumeration of the beds, but it represented a much more generalized aspect of the cliffs.

11 Thin and variable bed of very fine sand containing much comminuted shell. *The Pandora Bed* containing in abundance *Kellia ambigua*, *K. suborbicularis*, and *Odostomia*. *Pandora inequivalvis* is characteristic of this bed and had not been observed in any other division . . . . . 1·0 to 6 in.

12 Sandy crag, fine or coarse, with comminuted shells. Oblique bedding dipping into the face.

13 Beautifully preserved shells are very numerous in this bed, especially *Actaeon Noë*, *Trochus*, *Pholas cylindrica*, *Columbella sulcata*, and *Lima loscombii*. Actaeon is relatively abundant here though rare in other beds. The *Actaeon Bed*

14 Fine sand with *Echinus henslovii*, and an undescribed *Echinus*, a large *Balanus*. The *Echinus*, *Balanus Bed*.

15 The main *Grey Bed*. Characterized the upper part *Neptunea contraria*, and throughout by the occurrence of *Pectunculus glycimeris* (double), *Buccinum undatum* and *Pholas crispata*. Many ramose concretions near the base.

No separate dimensions can be assigned to beds 11, 12, 13, 14, 15 which, however, aggregate . . . . 6·0

16 *Sporadic coprolite layer.*

17 London Clay.

The beds which overlie the Crag at this place can be dismissed with a brief comment.

No. 1 was referred by Searles V. Wood, jun., to the "Middle Glacial of Essex", for whatever that may be worth.

No. 2. Searles Wood's note says, "The Warp ('y' of my Newer Pliocene Memoir). Very thin under the Tower, but thickening to 4 or 5 feet in the hollow under Walton, where in excavating for the first sea wall (destroyed in 1840) mammalian remains were found in it."

Nos. 3 and 4 were regarded by Prestwich as the Chillesford Clay and Chillesford Sand, an opinion in which I am unable to concur. The sand of No. 4 is coarse and angular and much mica is present. These characters alone would differentiate it from the Chillesford Sand. More decisive is the occurrence of fragments of wood in both 3 and 4 and of unworn flints in the clay.

Nos. 6, 7, and 8 are in close association, and though the presence of patches of comminuted shelly Crag in No. 6 is to be seen in only a few places the shells, which included *Pecten opercularis*, *Pinna*, *Pectunculus glycimeris*, *Pholas crispata*, *Cardita scalaris*, *Cardium* sp., *Artemis lentiformis*, *Astarte* (?) *obliquata*, *Mactra* (?) *arcuata*, and *Cerithium* sp. support Whitaker's[1] explanation of the decalcified condition in which this bed is usually found. In many places, where there had been a flow of water the shells had been wholly removed, the bedding was indistinguishable, and concretions of ironstone had been produced, while on each side shelly Crag was present. The three beds 6, 7, and 8 are to be regarded as one horizon characterized wherever fully developed by the occurrence of *Artemis lentiformis* and by the incoming of mollusca either absent from the beds below of great rarity at lower horizons.

They constitute the *Red Bed* of authors.

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[1] *Q.J.G.S.*, xxxvi, 1880.

Bed 9 forms a very well-marked horizon. It is obliquely bedded and is characterized by the occurrence of well preserved tests of the heart-shaped sea-urchin *Echinocardium cordatus.* I found at different places in the cliffs three perfect tests bearing the slender curved spines in their natural position. In no other division of the Walton Crag have I found such examples, and spines and fragments of tests which are of common occurrence in this bed and in the beds below are never in my experience to be found higher.

Bed 10 is a layer of Pectunculi associated with *Mactra arcuata.* The valves are almost always separate and generally lie with the concavity downward This may be an indication of beach conditions. Alfred Bell suggested that this layer is contemporaneous with a similar band overlying the " coprolite " deposits at Boyton and elsewhere which he regarded as the equivalent of the lower beds at Walton. I regard this correlation as untenable on several grounds : (1) That no Red Crag bed in Suffolk can be identified palaeontologically with the lower series at Walton. (2) Coprolites can be found in patches from end to end of the Walton Section and in all divisions. (3) The Pectunculi in this layer at Walton are prevalently of the variety *sub-obliquus* which is almost restricted to the Crag at Walton and finally, there are several Pectunculus bands at Walton of which this is the highest and the most constant.

No. 11 is a thin and irregular bed characterized by the abundance of small mollusca, especially the two Kellias, by the genus *Odostomia,* and most especially by the fragile Pandora which I have not found at any other level. At one place this bed is intersected by a layer of Pectunculi.

12 is sandy Crag, fine or coarse, with comminuted shells ; oblique bedding dipping into the face of the section.

13. Sandy Crag very rich in the beautifully preserved shells named. I have found this to be the only horizon at which *Actaeon* occurs at Walton. Robert and Alfred Bell,[1] however, speak of " beds of *Pectunculus*, *Artemis*, *Mactra* and another (rarely found) that may be called the *Actaeon* and *Echinus* bed. These occur in the order given, the *Pectunculus* band being the lowest." This is certainly contrary to my experience, as I have explained.

14. The fine sand No. 14 was in 1883 fairly easily recognized and was the source of the much prized *Echinus henslovii* and large *Balanus*, as well as an undescribed *Echinus*.

15. This is the Grey Bed of most writers but, as I hope to have shown, the term should be extended to all beds below No. 10.

16. An occasional layer of " Coprolites ".

17. The London Clay.

The section of the cliff which accompanies this description was obtained with much difficulty on account of the swampy and treacherous nature of the undercliff which in most cases interposes between the upper cliff of Crag and the beach. Frequent collapses of the ground renew from time to time the unstable tract of heterogeneous materials. In some cases the cliff descends " all-standing ", but more commonly, and especially in the deeper hollows, gravel, so-called Chillesford Beds, Crag, and London Clay are mingled together to produce a morass in which it is dangerous to become entangled. The present state (July, 1931) of the main section opposite the Tower is peculiarly dangerous.

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[1] *Proc. Geol. Assoc.*, ii, 1871, 192.

A. and R. Bell[1] drew a distinction between two Red Crag pits on opposite sides of the classic outcrop of Coralline Crag at Sutton and evolved a very ingenious explanation of the faunal contrasts which they present, which seemed to me highly artificial, and in my frequent conversations with Robert Bell he expressed the opinion that his brother was rather too imaginative. The salient features were that in the Bullock Yard Pit the fauna was of a much earlier type than that of the Riverside Pit, the one being characterized by more southern shells and the other by a relatively impoverished and more boreal suite. The necessary implication being that the Red Crag was capable of much closer and more intimate zoning than a literal interpretation of their two-fold classification would imply. (This, by the way, was very fully recognized by Harmer in his account of the Waltonian at Beaumont and Little Oakley.) Recent observations have given some grounds—perhaps not quite conclusive—for modifying my opinion.

When I resumed, in 1930, my interrupted study of the Pliocenes I endeavoured to carry out a long-cherished plan by which I thought a closer sub-division of the Red Crag beds could be effected, viz. by a census from pit to pit of the species belonging to genera selected for the probability that they would present significant differences consequent upon the substitution of more Recent and more northern forms for the more ancient and more southern.

Having in mind that at Walton the left-handed *Neptunea* was in sole posession of all the divisions below the Artemis Bed, and that only two individual shells of the right-handed *Neptunea* had ever been recorded from the highest horizon at Walton, I thought that I had here a statistical criterion by which to measure the relative ages of the Red Crag horizons. I therefore began a series of visits to such of the Crag exposures as still survive. My method was to collect every identifiable *Neptunea,* whether good or bad was immaterial so long as its left- or right-handedness could be made out.

In the course of this investigation I visited a number of pits, and found nothing that was very contrary to expectation—the proportions of rights to lefts were not very disharmonious with expectation.

Among the pits visited was an immense exposure at Newbourn and there, besides a fairly typical series of shells, I obtained 26 lefts and 13 rights — $\frac{2}{1}$.

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[1] *Proc. Geol. Assoc.*, ii, 1871, 190.

Two days later, having learned that there was another exposure of Crag near at hand, I went to the farm of Mr. Booth, where a fine scarp running the length of his stackyard gave excellent facilities for study of a richly fossiliferous exposure. *Neptuneas* occurred in scores, but to my great surprise I found that, in assiduous collecting of *every* specimen, two hours' work did not yield a single right-handed shell! A further hour's search yielded a total of 203 " lefts " to 2 " rights " – $\frac{203}{2}$.

In many other particulars this exposure presented a very marked contrast to that at the great pit, notably in the large number of *Cyprinas* (*Arctica*).

This experience may perhaps lead to a revision of my judgment regarding the pits at Sutton, but it would need to be supplemented by or contrasted with the evidence of other genera.

The reliance to be placed upon the judgment of the palaeontologists who have written on the Pliocene mollusca is necessarily a matter of the appraisement of their temperamental characteristics and as I have known, more or less intimately, all except Searles V. Wood the elder, I may be allowed to put on record my opinion.

Searles V. Wood the elder, the writer of *The Crag Mollusca*, was already an authority upon our Lower Tertiary fossils, though their description in the monographs of the Palaeontographical Society was not undertaken until the monograph on Crag Mollusca was far advanced.

Prestwich, whose second excursion into Pliocene Geology was in the year 1855, when his description of the Diestian outliers at Lenham and Harrietsham appeared, relied upon Searles Wood for the determination of the fossils. Wood no doubt was regarded as the most competent authority at that time by virtue of his interest in both the Lower and the Upper Tertiaries. For the list accompanying Prestwich's great paper on the Crags[1] Gwyn Jeffreys was responsible, and I am disposed to think that the transference was not wholly unconnected with the rejection of a paper offered by Searles Wood the younger to the Geological Society. I have a privately printed copy of the paper and the grounds of its rejection were very greatly resented by the author.

Gwyn Jeffreys was, as he told me, " a species breaker, rather than a species maker," which meant that his disinclination to create new species prompted him to, as I think, strain a definition so as to bring a shell within the limits of an existing species rather than to make a new one. Many of his determinations were, I think, affected by this excess of caution.

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[1] *Q.J.G.S.*, xxvii, 1871, 115, 325, and 453.

Robert G. Bell erred, if at all, on the side of caution, but my impression is that his judgment was remarkably cool and his very great experience as a collector of Crag fossils at a time when Coprolite digging gave great opportunities to the collector enabled him to form a sound opinion on the range of specific variation. He was, as his writings showed, a collector of British and Northern recent mollusca, and he was in frequent communication with malacologists at home and abroad.

Alfred Bell was a collector, and the wide range of his knowledge of Tertiary fossils led him to make bold and generally successful " shots " at specific determinations. He found a ready market for new species, especially with Dr. Reed, of York. I suspect that this was an inducement to rather wire-drawn distinctions. Unfortunately the present *locus* of many of his types is not now discoverable. That he had in very high degree the discriminating eye is beyond question.

F. W. Harmer was associated with Searles Wood the younger in the heroic enterprise of the first mapping on the large scale of Glacial deposits, and he remarked to me that the younger men of the Geological Survey had to thank this demonstration for the fact of their appointment. Harmer's intimate association with Wood was maintained until his friend's health broke down and their long association as field geologists came to an end. Wood died in 1885. It may be remarked that though a confirmed invalid, Wood continued to read and reflect upon geological problems ; his last paper, on the Pliocenes of St. Erth, was written while absolutely bedridden. Harmer's Crag work, lacking the stimulus of Wood's friendship, suffered an interruption of several years, during which he devoted himself to politics and became Mayor of Norwich. His renewal of interest in Crag geology dates from the Ipswich meeting of the British Association when I had the great pleasure of meeting him. From that time onward Harmer worked assiduously at geology and produced the long list of papers and the great monograph of the Pliocene Gastropoda associated with his name.

Harmer's association with Alfred Bell enabled him to draw largely upon Bell's extraordinary familiarity with Tertiary fossils and to trace obscure species and varieties. Of this help Harmer made full and handsome acknowledgment in the monograph, and Bell was entrusted with its completion after Harmer's death in his 88th year, so far as concerns the Gastropoda.

In the " preface " dated September, 1924, Alfred Bell explains that it was the intention of Mr. Harmer and himself to " write a joint memoir on the Pelecypoda ". He further remarks that " The oysters, of which I have photographs of sixty well-marked forms, are now being worked out by myself ". This enterprise was frustrated by Bell's own death at the age of 90.

I have quoted Bell at this length as throwing light upon remarks of Harmer that seem to me to require some elucidation. On p. 496

of his Pliocene Mollusca, he says "I have obtained between 600 and 700 species and well-marked varieties of mollusca within an area of twenty square yards at this truly prolific spot", which he describes as "only 1 or 2 feet of dirty-looking horizontally bedded Crag". If Alfred Bell could sub-divide the Pliocene oysters into sixty well-marked forms it is not difficult to understand why Harmer could find in a deposit of the limited thickness of the Little Oakley Crag "between 600 and 700".

In contrast to this Gwyn Jeffreys enumerates no more than 350 species and varieties (many characterized only by colour, which, of course, would not appear in the fossils) from the whole of the British seas from the Channel Islands to the Shetlands under every variety of environment from rocky shore down to the depth of 100 fathoms or more.

Harmer's well-known views regarding the influence of the prevailing winds affords a partial explanation of the discrepancy, but I am constrained to attribute much to an over-generous definition of a "well-marked variety".

MOLLUSCA.

Two asterisks indicate the occurrence in both the Artemis and the Grey Bed.

One asterisk on the *right* Grey Bed alone.

One asterisk on the *left* Artemis Bed alone.

Absence of an asterisk is to indicate that the source of the species has not been identified.

The list which follows comprises all the shells collected by me down to 1884. The generic names are as in S. V. Wood's Monograph except where otherwise stated.

*	*	*Ovula spelta* Linn = *O. Leathesii* J. Sow.
*	*	,, *brevior var.* S. V. Wood.
*	*	*Cypraea avellana* J. Sow.
*	*	,, *europea* Mont.
	*	*retusa* J. Sow.
*	*	*Erato laevis* Don.
	*	,, *maugeriae* Gray.
*	*	*Voluta lamberti* J. Sow.
	*	*Ancillaria* sp.
*	*	*Columbella compta* Bellardi (two specimens).
*	*	,, *sulcata* J. Sow.
	*	,, ,, var. *abbreviata* A. Bell.
	*	,, *sulculata* S. V. W.
		,, *Borsoni* (?) *bellardi*.
		,, *scripta* (? *vide* R. Bell).
*	*	*Nassa labiosa* J. Sow.
	*	,, *limata* Chemn.
*	*	,, *propinqua* J. Sow.
*	*	,, *elegans* Leathes.
*	*	,, *granulata* J. Sow., Pacific.
		Nassa conglobata Brocchi (*Desmonlea*, an African type).
*	*	,, *reticosa* J. Sow.
*	*	,, *granifera* Dujard.
	*	,, *ascania* ? = *pusillina*.
*	*	*Terebra canalis* S. Wood.
*	*	,, *inversa* Nyst.
*	*	*Buccinopsis dalei* J. Sow.
*	*	*Buccinum undatum* Linn.
*	*	*Purpura lapillus* Linn. (Taken in Atlantic as far south as Morocco.)
*	*	,, *incrassata* J. Sow., Vancouver.
*	*	,, *tetragona* J. Sow.
*		,, ,, *var. alveolatum* J. Sow
	*	*Rostellaria* "Derived probably from Eocene".
*	*	*Cassidaria bicatenata* J. Sow. (fragments only).
*		*Ringicula buccinea* J. Sow.
*	*	*Murex tortuosus* J. Sow.
*		,, *reedii* or *canhami* S. V. Wood.

*	*	*Fusus consociale* S. Wood.
*	*	*Trophon alveolatum* J. Sow.
*		,, *antiquum* (dextral form) Linn. (two specimens in *Artemis Bed*.
*	*	,, ,, (sinistral form) found living at Vigo.
*	*	,, *costiferum* Nyst.
*	*	,, *gracile* Da Costa.
*		,, *cordatum* A. Bell.
	*	,, *barvicensis* Johnston.
*	*	,, *muricatum* Mont.
		,, *propinquus* Alder.
		,, *jeffreysianus* Fischer.
		Pyrula acclinis S. V. W. = *P. reticulata* Lam., in a boxstone.
	*	*Clavatula* (*Defrancia*) *hystrix* Jan.
*		,, *Leufroyi* Michaud.
	*	,, *linearis* Mont.
	*	,, *philberti* Michaud.
*	*	,, *reticulata* Renier.
	*	*Pleurotoma cancellata* J. Sow.
*	*	,, *laevigata* Phil.
*	*	,, *mitrula* J. Sow.
*	*	,, *costata* Da Costa
*	*	,, ,, var. *coarctata* Forbes.
*	*	,, *tenuistriata* A. Bell.
		,, *boothii* Smith.
	*	,, *nebula* Mont.
		,, *turrifera* Nyst.
	*	,, *pannus* Bast. ("derived from Cor Crag").
	*	,, *porrecta* (*nivalis*) S. Wood
	*	,, *senilis* S. Wood.
*		,, *interrupta*.
	*	*Bela turricula* Mont.
	*	,, *rufa* Mont.
	*	,, *Trevelyana* Turt.
	*	*Conopleura crassa* A. Bell.
	*	,, *brachystoma* Wood.
*		,, *icenorum* (?) Wood.
		,, *modiola* Jan. ("*carinata* according to Wood").
		,, *perpulchra* Wood.
	*	*Cancellaria coronata* Scacchi.
	*	,, (*Admete*) *reedii* A. Bell.
*	*	*Cerithium tricinctum* Brocchi.
*	*	,, *variculosum* Nyst.
		,, *reticulatum* ("var. of *variculosum*, according to Wood").
*	*	,, *perversum* Linn. = "adversum".
	*	,, *trilineatum* Phil.
*	*	,, *granosum* S. V. Wood.
		,, *adversum* Mont.
*	*	*Cerithiopsis metaxae D. Chiajii* = ? *tuberculare*.
	*	*Cerithiopsis tubercularis* Mont., one specimen much worn.
	*	*Caecum mamillatum* S. Wood.
*		*Aporrhais pes-Pelicani* Linn.
*	*	*Turritella incrassata* J. Sow.
*	*	,, *tricarinata* Brocchi (perhaps var. of *T. terebra*).
	*	,, *subangulata* Brocchi.
*		,, *imbricataria* Lam. ?
*		,, *terebra* Linn. = *T. communis* Risso.
*	*	,, *planispira* S. Wood.
	*	,, *bicincta* S. V. Wood.
	*	*Menestho jeffreysii* A. Bell.
		,, *albula* Fabr.
*	*	*Scalaria funiculus* S. Wood = *S. pumicea* Brocchi.
*	*	,, *subulata* J. Sow.
	*	,, *fimbriosa* Wood.
	*	,, *foliacea* J. Sow.
	*	,, *cancellata* Brocchi.
*		,, *varicosa* Lam. (Wood says = *funiculus*).
*		,, *variculosa*.
	*	*Pyramidella leviuscula* S. Wood.
	*	*Chemnitzia elegantior* S. Wood = *C. lactea*.
*	*	,, *internodula* S. Wood.
	*	,, *communis* Risso (Wood says ?).
	*	,, *indistincta* Alder.
?	*	,, ? *plicatula* Brocchi.
	*	,, *rugulosa* S. Wood.
	*	,, *filosa* S. Wood.
		,, *densecostata* Phil.
*	*	*Eulimella acicula* Phil. (not *Chem. similis*, according to Wood).
	*	*Odostomia plicata* Mont.
	*	,, *conoidea* Mont.
	*	,, *acuta* Jeff.
	*	,, *umbilicaris* ?
	*	,, *truncatula* Jeff.
	*	*Eulima distorta* Deshayes.
	*	,, *subulata* Mont.
	*	,, *intermedia* Cantraine.
*	*	,, *polita* Linn.
	*	,, *hebe* Wood.
*	*	*Eulimene pendula* S. V. Wood ("Paludestrina")
*	*	,, *terebellata* Nyst.
*	*	*Lacuna suboperta* J. Sow.
		Littorina litorea Linn. (? M. and M.).
	*	*Rissoa stefanisi* Jeff.
	*	,, *zetlandica* Mont.
	*	,, *reticulata* Mont.
	*	,, *abyssicola* Forbes.
	*	,, *curticostata* S. V. Wood = *semicostata* S. Woodward.
*	*	*Natica catenoides* S. Wood (*N. heros* Say, an American species).

* * *Natica catena* Da Costa.
* * ,, *hemiclausa* J. Sow.
* * ,, *multipunctata* S. Wood (*millepunctata* Lam.").
* * ,, *varians* Dujard.
* ,, *clausa* Brod. and Sow. ("one specimen only in Mr. Greenwood's collection").
* * *Vermetus intortus* Lam.
* ,, *subcancellatus* Biv. = *glomeratus* Bav.
* *Trochus bullatus* Phil.
* * ,, *cinerarius* Linn.
* * ,, *cineroides* S. V. Wood.
* ,, *formosus* Forbes (= "*occidentalis* Mighels").
* ,, *multigranus* S. Wood.
* * ,, *noduliferens* S. Wood.
* * ,, *granulatus* ? Born (var. of *T. noduliferens*).
* * ,, *subexcavatus* S. Wood (var. of *T. noduliferens*).
* * ,, *adansoni* Payr.
* * ,, *millegranus* Phil.
* * ,, *tumidus* Mont.
* ,, *kickii* Nyst.
* ,, *montacuti* W. Wood.
* * ,, *zizyphinus* Linn.
* * ,, *conulus* Linn.
* *Adeorbis subcarinatus* Mont.
* * *Fissurella graeca* Linn.
* * *Emarginula fissura* Linn.
* ,, *crassa* J. Sow.
* * *Calyptraea sinensis* Linn. (The northern limit is Dublin Bay and Milford Haven.)
* * *Capulus ungaricus* Linn.
* ,, *militaris* Mont. (= *recurvatus* S. W.).
* * ,, *obliquus* S. Wood.
* ,, *unguis* Sow.
* *Brocchia sinuosa* Brocchi.
* ,, *partim-sinuosum* Wood.
* * *Tectura virginea* Müll.
,, *fulva* Müll.
Lepeta caeca Müll.
* *Chiton* sp.
* * *Actaeon noae* J. Sow.
* ,, *tornatilis* Linn.
* ,, *etheridgii* A. Bell (?).
,, *subulatus* S. V. Wood.
,, *exilis* (= ? *etheridgii vide* Wood).
* *Cylichna cylindracea* Penn.
* * *Conovulus pyramidalis* J. Sow.
* ,, *fusiformis*.
Hydrobia ulvae Penn (? "*vide* Wood")
* *Helix rysa* S. Wood.
* *Helix incarnata* Müller (continental shell).
* ,, *lactea* Müll.
,, *lens* Férussac.
* * *Dentalium rectum* Gmelin.
* * ,, *dentalis* Linn.

Lamellibranchiata.

* * *Anomia patelliformis* Linn.
* ,, ,, var. *striata* Brocchi.
* * ,, *ephippium* Linn.
* ,, var. *aculeata* (?).
* * *Ostrea edulis* Linn. (Wood says this is *O. ungulata* Nyst in Red Crag).
* ,, *cochlear* Poli.
* *Pecten dubius* Brocchi.
* * ,, *opercularis* Linn. var. *gracilis* ("In Iceland").
* * ,, *pusio* Linn.
* * ,, *tigrinus* Müll. ("In Iceland").
* * ,, *maximus* Linn.
* ,, *westendorpianus* Nyst.
* *Lima exilis* Wood.
* * ,, *loscombii* G. B. Sow.
* ,, *squamosa* Lam. ("one specimen only").
* ,, *ovata* S. Wood.
* *Pinna* (? "*rudis*") Linn.
,, *pectinata* Mont. ("? *vide* Wood").
* * *Mytilus edulis* Linn.
,, *edulis* var. *angulata* Linn.
,, ,, ,, *galloprovincialis* Lam.
* *Mytilus barbata* Linn.
* *Modiolaria costulata* Risso.
,, ,, and var.
* * ,, *petagnae* Risso.
* ,, *marmorata* Forbes.
* ,, *discors* Linn.
* * *Arca lactea* Linn.
* ,, *tetragona* Poli.
* * *Pectunculus glycimeris* Linn. d.v.
,, ,, var. *subobliquus* S. V. W.
* *Limopsis pygmaea* Phil.
* * *Nucula laevigata* Munst.
* * ,, *nucleus* Linn.
* ,, *tenuis* Mont. ?
,, *cobboldiæ* J. Sow. ("one specimen only").
* *Leda* sp.
* *Montacuta bidentata* Mont.
* ,, *ferruginosa* Mont.
* *Kellia suborbicularis* Mont.
* *Scacchia elliptica* Phil.
* *Lepton deltoideum* S. Wood. ("In S. V. Wood's collection")

	*	*Scintilla ambigua* Nyst.
*	*	*Lucina borealis* Linn.
	*	,, *decorata* S. Wood.
*	*	*Cardita corbis* Phil. (d.v. in Artemis Bed).
*	*	,, *scalaris* Leathes.
*	*	,, *senilis* Lam.
*		,, *obicularis* Leathes.
		,, *anceps* Wood (S. V. W. " ? ")
		,, *chamæformis* Leathes (S. V. W. " ? ").
*	*	*Cardium edule* Linn.
	*	,, *fasciatum* Mont.
*	*	,, *nodosum* Turt. (d.v. in Artemis Bed).
*	*	,, *parkinsoni* Sow.
	*	,, *venustum* Wood (" decorticatum ? ").
*		,, *decorticatum* = *interruptum* S. Wood.
	*	,, *strigilliferum* S. Wood.
*		,, *angustatum* J. Sow. (" one doubtful specimen at Walton ").
	*	,, *norvegicum* Spengler.
		,, *pinnatulum conr.* = *nodosum*.
	*	*Erycinella ovalis* Conrad.
*		*Cyprina rustica* Sow. (one specimen only).
*	*	,, *islandica* Linn.
*		*Astarte compressa* Mont.
*		,, *crebrilirata* S. V. Wood. (" not *depressa* Brown, nor *crebricostata* Forbes ").
*	*	,, *obliquata* J. Sow.
	*	,, *triangularis* Mont.
	*	,, *galeottii* Nyst.
	*	,, *pusilla* Forbes.
*		,, *sulcata* Da Costa.
*		,, *burtini* Laj.
*	*	,, *omalii* Laj.
*	*	,, *basterotii* Laj.
		,, *forbesi* S. Wood.
*	*	*Woodia digitaria* Linn d.v. " Valves have been found in Cornwall."
*		*Isocarida cor.* Linn.
*		*Chama gryphöides* Linn. (one specimen).
*	*	*Venus imbricata* J. Sow.
	*	,, *ovata* Penn.
	*	,, *fasciata* Da Costa.
*		,, *casina* Linn.
	*	*Circe minima* Mont.
*	*	*Cytherea rudis* Poli.
*	*	*Artemis lentiformis* J. Sow. = *Venus lentiformis* L.
*	*	,, *lincta* Pult.
	*	*Tapes texturata* Lam.
	*	*Zapes virginea* Linn.
*		,, *pullastra*. Mont.
*	*	*Venerupis irus* Linn.
*	*	*Gastrana laminosa* J. Sow.
	*	*Donax politus* Poli.
		Tellina crassa Penn.
		,, *benedenii* Nyst (" a fragment ").
		,, *obliqua* J. Sow. (" found July, 1878, R. B.").
*		,, *lata* Gmelin.
		,, *calcaria* Chem. (" ? in M. and M. collection ").
*		,, *donacina* Linn. (" Harmer doubts this ").
		,, *pretenius* Leathes (" S. V. W. doubts this. It is a solitary example ").
	*	*Psammobia ferroensis* Chem.
*	*	*Abra alba* W. Wood.
	*	,, *fabalis* S. Wood.
	*	,, *prismatica* Mont.
		Mactra stultorum Linn. (S. V. Wood puts " ? " against this).
*	*	,, *arcuata* J. Sow.
		,, *truncata* Mont.
		,, *deaurata* Turton " ? American species".
	*	,, *glauca* Born. " Harmer says = *arcuata*, an opinion I cannot endorse. The hinge is very different. S. V. W. agrees with me."
*		,, *solida* Linn. = *ovalis*.
	*	,, *subtruncata* Da Costa.
	*	,, *constricta* —— (R. G. B. puts a ? against this horizon).
		Lutraria elliptica Lam.
	*	*Cochlodesma complanata* S. Wood.
	*	*Pandora inequivalvis* Linn.
	*	*Poromya granulata* Nyst.
	*	*Cultellus cultellatus* S. Wood.
*	*	*Solen gladiolus* Gray (R. G. B. = *siliqua*).
*	*	,, *ensis* Linn.
*	*	*Corbula gibba* Olivi.
*		,, *striata*.
*	*	*Corbulomya complanata* J. Sow.
	*	*Sphenia binghami* Turton.
	*	*Saxicava arctica* Linn.
*	*	,, *rugosa* Penn.
	*	*Panopaea faujasii* Menard.
*		,, *norvegica* Spengler.
*		*Glycimeris angusta* Nyst (two specimens).
*	*	*Mya arenaria* Linn.
*	*	,, *truncata* Linn.
*	*	*Pholas crispata* Linn.
*	*	,, *cylindrica* Sow.

* *Pholas parva* Penn.
,, *dactylus* Linn.
Teredo norvegica Speng.
Gastrochaena dubia Penn.

Brachiopoda.

* * *Terebratula grandis* Blum.

Prestwich adds—
Buccinum glaciale Linn. (also in *Pliocene Memoir*).
Cerithium trilineatum Ph. (var. *inversum*).
,, *variculosum* *C. reticulatum* var.
Chemnitzia elegantissima.
Clavatula boothii = *Defrancia reticulata* var.
Odostomia plicatula Brocchi.
,, *unidentata.*
Pyrula acclinis = *P. reticulata.*
Pyramidella uniplicata = *P. plicosa.*
Trochus cinerarius = *T. cineroides* var.
,, *papillosus.*
,, *subexcavatus* = *T. papillosus* var.
Paludestrina pendula = *P. terebellata var.*
Trophon antiquum. No mention of the *sinistral Trophon.*

Lamellibranchs.

Cardium parkinsoni = *C. nuttalii* Conr.
,, *venustum* = *C. norvegicum* var. *rotunda.*
Cochlodesma complanatum = *Thracia praetenius* Pult. var.
Corbula striata = *C. gibba* Olivi.
,, *tenuis.*
Leda pygmaea Münst.
Lima pygmaea.
Mactra arcuata = *M. glauca* var.
,, *ovalis* = *M. solida* var. *elliptica.*
,, *truncata* = *M. solida* var.
,, *deaurata* = *M. solida* Munstr.
Pandora pinna = *P. inequivalvis* Linn. var.
Pecten gracilis = *P. opercularis* var.
Solen siliqua Linn.
Tellina praetenuis = *T. calcaria* var.
Venus imbricata = *V. fasciata* var.

Searles V. Wood adds—
Eulima similis d'Orb.
Eulimella acicula Phil.
Natica helecina Brocchi.
Trochus papillosus (?) Da Costa.
Pyrula reticulata Lam.
Kellia ambigua Nyst.
Corbula striata Walker and Boys.
,, *complanata* J. Sow.
Odostomia unidentata Mont.
Mactra truncata Mont.
Cultellus cultellatus Phil.
Pleurotoma gracilior.

Harmer adds 65 to my list:—
Rostellaria (*Rimella*) *gracilenta* S. V. Wood.
Nassa reticosa var. *costata* S. V. Wood.
,, *microstoma* S. V. Wood.
,, *consociata* S. V. Wood.
,, *dautzenbergii* Harmer var. *simplex* S. V. Wood.
,, ,, var. *minuscula* Harmer.
,, cf. *Edwardsi* Fischer.
Baccinum undatum var. *pulchra* Harmer.
,, *inexhaustum* Verkrüzen.
,, *meridionale* Verkrüzen var. *inflata* Harmer.
,, *totteni,* Stimpson.
Searlesia costifer var. *islandica* Harmer.
,, *björnsoni,* Mörch and Poulsen.
,, *lundgreni* Mörch and Poulsen.
Trophon clathratus Linn. = *scalariforme* Gould.
,, *muricatus* var. *similis* Harmer.
Neptunea contraria var. *sinistrorsa.*
,, *contraria* var. *angulata* Harmer.
,, ,, *informis* Harmer.
,, *despecta* Linn. Unique. *decemsostata* Say.
Sipho curtus Jeffreys.
,, *togatus* Mörch.
Pleurotoma inermis Partsch.
Drillia incrassata var. *crassa* A. Bell.
Spirotropis modiola Jan.
Clathurella linearis var. *aequalis* Jeff.
,, *cordieri* Payr.
Mangilia smithii Forbes.
,, *indistincta.*
Rhaphitoma attenuata var. *gracilior* A. Bell.
,, *valida* Harmer.
Columbella erythrostoma Bonelli.
Ocinebra aciculata.
Brocchinia mitraeformis Brocch.
Sveltia lajonkairei Nyst.
Admete viridula Fabr.
Bittium punctulum S. V. Wood.
Triforis perversa Linn.

Turritella (*Haustator*) *vermicularis* Brocch. *lineolato-cincta* Sacco.
,, (*Haustator*) *vermicularis*
Vermetus bognoriensis Mantell.
Trivia retusa var. *angliae* S. V. Wood.
,, *affinis* Dujard.
Ficula condita Brongn. = *F. reticulata*.
Turbonilla paucistriata Jeff.
,, *varicula* S. V. Wood., var. *expansa* Harmer.
,, *internodula* S. V. Wood, var. *conica* Harmer.
Eulima stenostoma Jeff.
Eulimene grandis A. Bell.
Alvania punctura Mont.
Natica multipunctata var. *consors* S. V. Wood.
Natica helicina (Brocchi) Sacco.
,, *alderi* Don.
,, *exvarians* Sacco.
Trochus conuloides Lam.
,, *zizyphinus* var. *laevigat* J. Sow.
,, ,, var. *dilatata* Monterosato.
Solariella macula S. V. Wood.
Fissurella italica Defr.
Emarginula crassalta S. V. Wood.
Alexia myosotis Drap.
Ringicula ventricosa J. Sow.
Odostomia unidentata Mont.
Turbonilla discrepans Harmer *Chemnitzia plicata* pars.
Caecum glabrum Mont.

Foraminifera from a sample of Grey Sand, identified by E. Halkyard (Knutsford).

* *Biloculina ringens* Lamk.
* *Miliolina auberiana* d'Orb.
* ,, *subrotunda* Mont.
* ,, *semilunum* Linn.
* *Textularia sagittula* Defr.
* ,, *gramen* Lam.
* *Bolivina dilatata* Reuss.
* *Cassidulina laevigata* d'Orb.
* ,, *crassa* d'Orb.
* *Lagena orbignyana* Seg.
* ,, *hexagona* Will.
* ,, *sulcata* W. and J.
* ,, *marginata* Mont.
* ,, *squamosa* Mont.
* ,, *ornata* Will.
* ,, *williamsoni* Alcock.
* ,, *clathrata* Brady.
* ,, *castrensis* Schwager.
* ,, *costata* Will.
* ,, *clavata* d'Orb.
* *Nodosaria pauperata* d'Orb.
* *Rhabdogonium tricarinatum* d'Orb.
* *Polymorphina compressa* d'Orb.
,, *lactea* W. and J.
* ,, *problema* d'Orb.
* ,, *gibba* d'Orb.
* ,, *longicollis* Brady.
* ,, sp.
* ,, sp.
* ,, sp.
* *Uvigerina angulosa* Will.
* ,, *pygmaea* d'Orb.
* *Globigerina bulloides* d'Orb.
* *Discorbina bertheloti* d'Orb.
* ,, *parisiensis* d'Orb.
* ,, ? *sauleii* d'Orb.
* ,, *rosacea* d'Orb.
* *Planorbulina mediterranensis* d'Orb.
* *Truncatulina lobatula* W. and J.
,, *ungeriana* d'Orb.
* *Pulvinulina karsteni* Reuss.
* *Rotalia beccarii* Linn.
* ,, *calcar* d'Orb.
* *Nonionina depressula* W. and J.
* ,, *scapha* F. and M.
* ,, ? *boneana* d'Orb.
* *Polystomella striato-punctata* F. and M.
* ,, *crispa* Linn.
* ,, *macella* F. and M.

The *Pliocene Memoir* adds—
Biloculina elongata d'Orb.
Calcarina rarispina d'Orb.
Lagena melo d'Orb.
Miliolina semilunum Linn.
Nonionina faba F. and M.
Polymorphina complanata d'Orb.
Pullenia sphaeroides d'Orb.
Truncatulina refulgens Mont.
Uvigerina irregularis Brady.

Spongida.

Cliona celata Grant.
S. V. Wood adds *Grantia compressa* Flem., *Ann. and Mag.*, xiii, 10.

Hydrozoa.

Hydractinia circumvestiens.

Corals.

Cryptangia woodii E. and H.
Balanophyllia calyculus S. V. W.

Sphenotrochus intermedius Münst.
,, *boytonensis* Tomes.

The *Pliocene Memoir* adds—
Trochocyathus anglicus Dunc.

Polyzoa.

Hornera pertusa Busk.
* ,, *frondiculata* Lamour.
,, *reteporacea* M. Ed.
* ,, *infundibulata* Busk.
Tubulipora phalangea Couch.
,, *flabellaris* Johnst.
Lepralia punctata Hassall.
,, *puncturata* S. Wood.
,, *mamillata* S. Wood.
,, sp. nov.
* ,, *violacea* Johnst.
,, *ciliata* Linn.
* ,, *bicornis* Busk.
,, *ansata* Johnst.
,, *peachii* Johnst.
* *Membranipora tuberculata* Bosc.
,, *trifolium* S. Wood.
,, *monostachys* Busk.
,, *pouilletii* Aud.
,, *bidens* Hag.
,, *oblonga* Busk.
,, *holostoma* S. Wood.
Hippothoa abstersa S. Wood.
Alecto repens S. Wood.
,, *dilatans* Johnst.
Eschara sinuosa Busk.
,, *sedgwickii* M. Edw.
,, *monilifera* M. Edw.
,, *porosa* M. Edw.
Cellepora pumicosa.
,, *parasitica* Michel.
,, *caespitosa* Busk.
,, *coronopus* S. Wood.
,, *compressa* Busk.
,, *edax* Busk.
,, *tubigera* Busk.
,, *ramulosa* Linn.
Lunulites conica Defr.
Cupularia denticulata Conrad.
,, *canariensis* Busk.
Heteroporella parasitica Busk.
,, *radiata* Busk.
Heteropora clavata Goldf.
Salicornaria crassa S. Wood.
,, *sinuosa* Hassall.
* *Melicerita charlesworthii* M. Edw.
Fascicularia aurantium M. Edw.
,, *tubipora* Busk.
* *Alveolaria semiovata* Busk.
Retepora beaniana King.
Mesenteripora meandrina S. Wood.
Diastopora simplex Busk.
Idmonea delicatula Busk.
Pustulopora sp.
Discoporella (*Lichenopora*) *grignonensis* M. Edw.

The *Pliocene Memoir* adds—
Hornera rhomboidalis Busk.
,, *striata* M. Edw.
Lepralia infundibulata Busk.
,, *lobata* Busk.
,, *unicornis* Johnst.
Alysidota labrosa Busk.
Cellepora scruposa Busk.
Biflustra delicatula Busk.
Hemeschara imbellis Busk.
Heteropora pustulosa Busk.
Retepora simplex Busk.
Membranipora dubia Busk.
,, *savartii* Aud.
Defrancia rugosa Busk.
Reptomulticava macropora d'Orb.

G. W. Bell (?) adds—
Polyzoa.
Hornera rhipis Busk.
,, *striata* M. Edw.
Lepralia malusii Aud.
,, *pyriformis* S. V. W.
Hippothoa patagonica Busk.
Heteropora laevigata d'Orb.
,, *septosa.*
Fungella quadriceps Busk.
Idmonea fenestrata Busk.
Salicornaria rhombifera Munst. (I doubt this identification.—P.F.K.)

Annelids.

Spirorbis sp.
Cyclogyra multiplex S. Wood.
Ditrupa subulata Berk.

The *Pliocene Memoir* adds—
Ditrupa gadus Mont.
Serpula triquetra Linn.
,, *vermicularis* Linn.
Spirorbis carinatus Mont.

Echinodermata.

Echinus henslovii Forbes.
,, *woodwardi* Desh. ? or Desor.
Psammechinus pulchellus (*vide* G. W. Bell).
Echinarachinus woodii Forbes.
Echinocardium cordatum Penn.
Echinocyamus suffolciensis Agass.
,, *hispidulus* Forbes.
,, *pusillus* O. F. M.
,, *oviformis* Forbes.

Professor J. W. Gregory regards these four as varieties of *hispidulus* Forbes.

* *Goniaster.*
* *Pentacrinus subasaltiformis.*
* *Comatula* sp.
* ,, sp.
* ,, sp.
G. W. Bell adds *Psammechinus pulchellus.*
Professor J. W. Gregory adds *Spatangus purpureus* O. F. M. ?

The *Pliocene Memoir* adds—
Echinus miliaris Leske.
Temnechinus excavatus S. Wood.
,, *turbinatus* Forbes.
Uraster rubens Retz.
,, sp.
but omits to notice *Echinocardium cordatum*, which is the most abundant *Echinoderm* at Walton.

Cirripedia.

In the monograph of the *Cirripedia* by Charles Darwin six species of *Balanus* are recorded from the Red Crag, all from Sutton, but *Coronula barbata* is attributed to both Sutton and Bawdsey. No pedunculate *Cirripedes* are recorded from Walton.

From Walton-on-the-Naze Darwin recorded *Verruca stromia*, which I am able to confirm from my own collecting. It is convenient to mention here that I have found barnacles encrusting gastropod shells, viz. *Buccinopsis dalei*, *Trophon costiferum*, *Purpura lapillus*, *Purpura tetragona*, *Nassa reticosa*, and *Natica multipunctata*; but among the many thousands of *Neptunea contraria* I have examined not a single example bearing a barnacle. Whether this is due to the fact that the outer layer of the shell in this genus consists of calcite or not is an interesting question, but it should be remembered that the shell of *Purpura lapillus* is also of calcite composition yet it is commonly found to bear barnacles. [Harmer, however, said he had specimens of *Neptunea contraria* bearing barnacles.]

Marine crustacea.

Xanthopsis leachii (?).
Cancer pagurus Linn.
Carcinus maenas Linn.
Portunus depurator Leach.
,, *puber* Linn.
,, *corrugatus.*
Gonoplax angulata Leach.
Ebalia pennantii.
Pagurus bernhardus Fabr.

Ostracoda.

Bairdia subdeltoidea.
Candona laqueta Jones.
,, *trachypora* Jones.
Cytherideis tuberculata Jones.

Cirripedia.

Verruca stromia Müll.
Balanus porcatus Da Costa.
Balanus bisulcatus Nyst.
* ,, *tintinnabulum* Linn.
,, *crenatus* Brug.
,, *inclusus* Darwin.
,, *hameri* Ascan.
The *Pliocene Memoir* adds—
Balanus concavus Bronn.
,, *dolorus* Darw.
Coronula barbara Darwin.

Vertebrata.

Carcharadon megalodon Agass.
Oxyrhina hastalis Agass.
Lamna (*Otodus*) *obliquus* Agass.
Raia antiqua Ag.
Edaphodon sp.
Pristis sp.
Otoliths of Gadoid fishes.

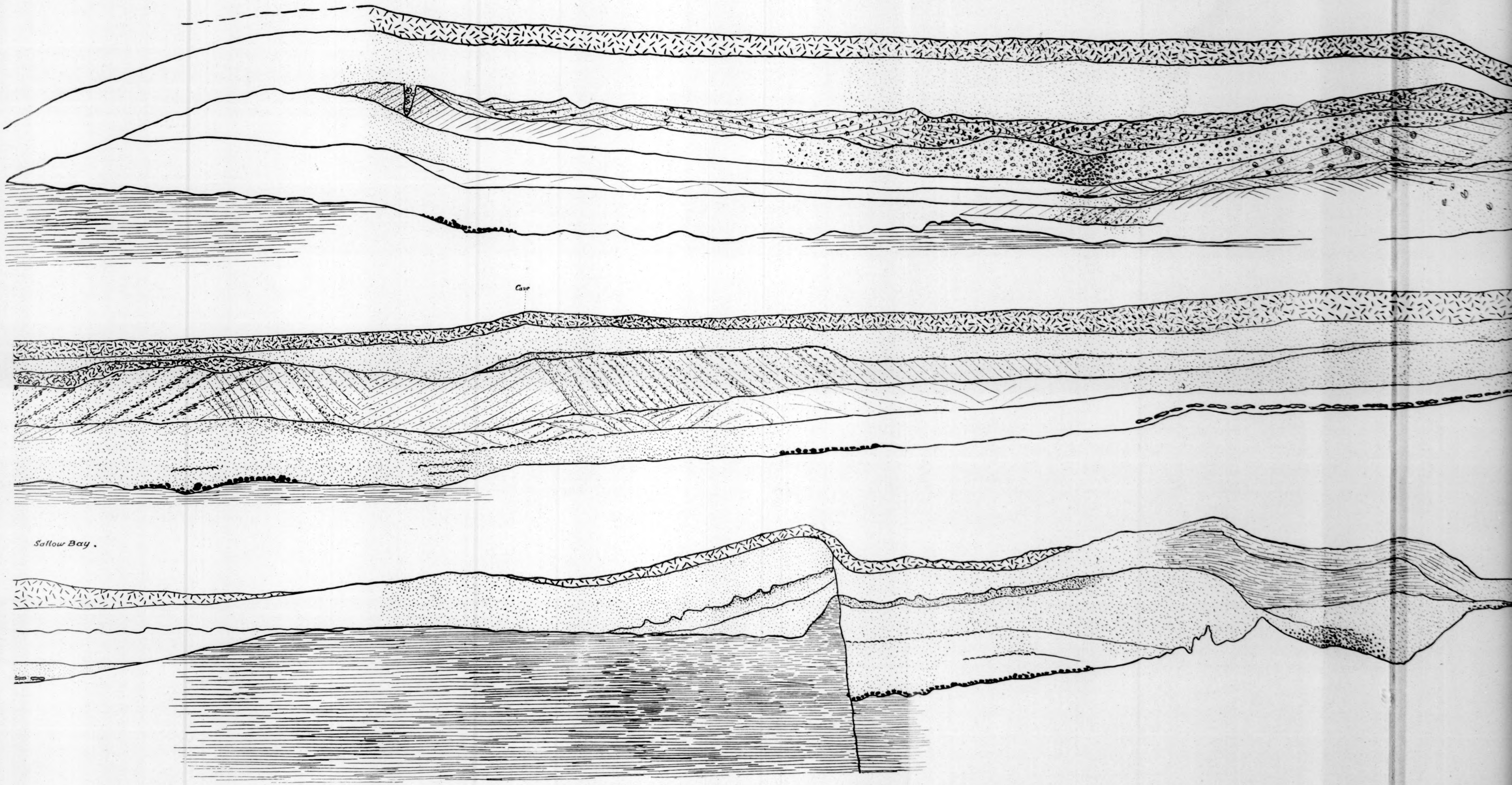
Cave
Sallow Bay.

Fig. 1.—FINISHED SECTION, RED CRAG, WALTON-ON-THE-NAZE.

The Avonian Inlier at Upper Vobster (Somerset).

By F. B. A. Welch, B.Sc., Ph.D., F.G.S., Carnegie Teaching Fellow, University of St. Andrews.

THE inlier of Carboniferous Limestone, situate within the Coal Measure area at Upper Vobster, was the subject of much controversy in the past. It was not, however, until 1912 that Dr. T. F. Sibly[1] settled this vexed question, and showed that the inlier was a mass of Carboniferous Limestone and "Millstone Grit" superimposed upon folded Coal Measures by thrust-faulting. His paper contains a very accurate map showing the extent of the quarries and strata exposed at the time: the latter now unfortunately having been removed by further quarrying.

The extensive quarrying that has taken place since that date has, however, revealed several points of interest, and since these are liable to be destroyed by further excavation or to become overgrown, it would appear desirable to record these observations which, briefly stated, are as follows:—

(1) Presence of further unsuspected thrust-faulting.

(2) Position of certain of Sibly's faults (surmised in 1912) now verified by actual exposure.

(3) Exposure of shale and quartzite beds yielding Goniatites of Halifaxian age (lower G zone of Bisat): this being the first record of goniatites from the Mendip area.

I wish to express my indebtedness to Mr. W. S. Bisat for the determination of the Goniatites, and to Dr. T. A. Ryder for the examination of certain Carcinophyllids. I would also thank the quarry officials for granting me access to their workings.

At the present day the limestone is quarried on a large scale at Vobster Quarry (Wainwrights Ltd.), and at the recently re-opened Bilboa Quarry (Beechams Ltd.). The former working is the more extensive, and in 1912 was the only quarry in work. It is from this locality that most of the facts below recorded have been obtained.

This quarry (see Map, Fig. 1) consists of two parts: Vobster Old Quarry on the south, separated by an east-west ridge from the present Vobster Quarry on the north. The old quarry is totally abandoned and the structure difficult to make out; and for a detailed account of its geology Sibly's paper[1] must be consulted. Briefly stated, this old quarry shows S_2 and D_1 beds (locally inverted) faulted against a mass of quartzites and shales ("Millstone Grit" auctt.) which forms the east-west ridge. On the north side of this

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[1] T. F. Sibly, "The Faulted Inlier of Carboniferous Limestone at Upper Vobster (Somerset)": *Q.J.G.S.*, lxviii, 1912, 58–74. This paper contains a full bibliography of literature prior to his investigations and accordingly, such a list will be omitted from the present communication.

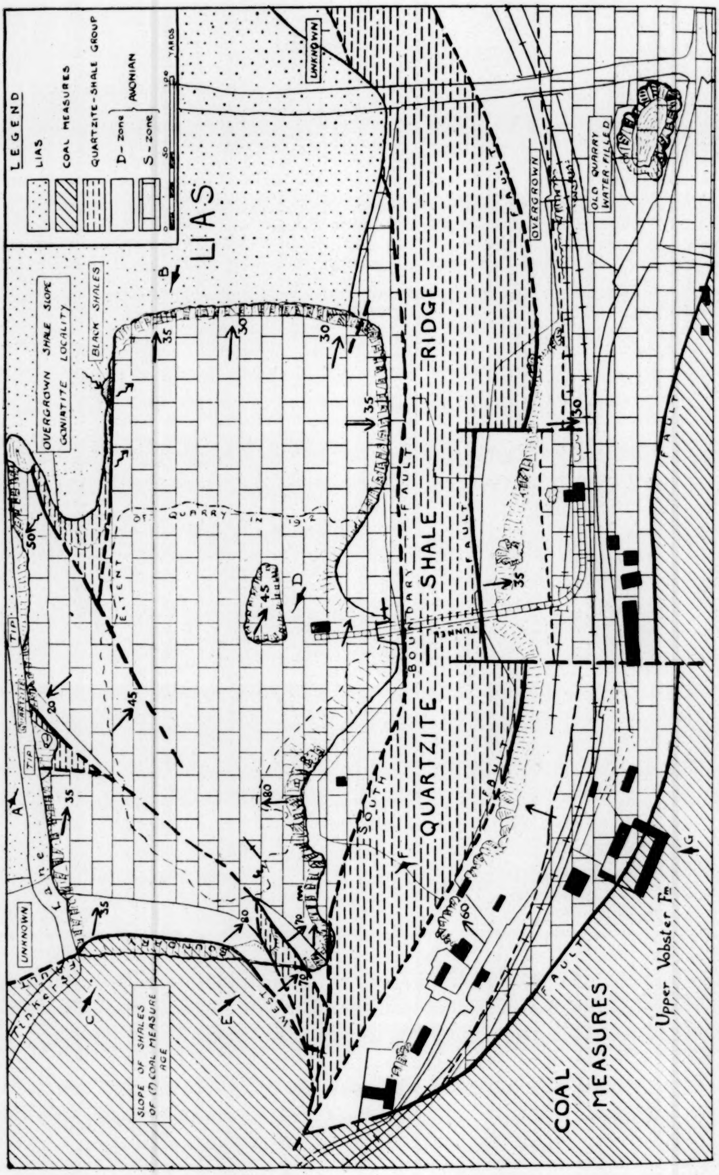
LEGEND
LIAS
COAL MEASURES
QUARTZITE-SHALE GROUP
D-zone
S-zone
AVONIAN
0
50
100
YARDS
LIAS
B
OVERGROWN SHALE SLOPE GONIATITE LOCALITY
BLACK SHALES
UNKNOWN
35
30
30
35
50
TIP
20
45
45
D
EXTENT OF QUARRY IN 1912
TIP
A
35
Lane
UNKNOWN
35
80
80
70
70
WEST BOUNDARY FAULT
Pinkers Fault
C
E
SLOPE OF SHALES OF (?) COAL MEASURE AGE
SOUTH BOUNDARY FAULT
QUARTZITE SHALE RIDGE
TUNNEL
FAULT
FAULT
FAULT
OVERGROWN
35
30
60
OLD QUARRY WATER FILLED
FAULT
FAULT
G
Upper Vobster Fm
COAL MEASURES

FIG. 1.—Map of the Vobster Quarries. (Adapted from Sibly.) Map oriented N.–S. Arrows with numerals indicate dips. Arrows with letters indicate points along lines of section seen in Fig. 2.

is a second area of limestone in which the present quarry is being excavated. Sibly's map (pl. ii)[1] shows that this limestone is separated from the quartzite-shale mass by a large fault running approximately east-west, and from the Coal Measures on the west by a second fault trending north-east to south-west. These two faults I have termed, for convenience, the South and West Boundary Faults respectively. The position of the latter Sibly could only infer; but since 1912 quarrying was continued until the Coal Measures were reached and to-day it is possible to trace this fault with accuracy, whilst additional faulting, hitherto unsuspected, has also been revealed.

DETAILS OF QUARRY AT PRESENT DAY (1931).

Vobster Quarry is roughly rectangular in shape and covers an area of approximately two acres. It has been worked throughout to a depth of 45–50 feet, and recently, near the tunnel on the south side, an excavation has been made in the floor to a further depth of about 25 feet.

East of a line drawn diagonally from the north-west to the south-east corner, some 3 feet of Lias rests unconformably upon the eroded and level top of the limestone. This overburden together with other quarry waste has been spread over the floor or tipped against the sides of the abandoned parts of the quarry: thus no rock can be seen in situ in the quarry floor (except in the new excavation). Exposures are therefore confined to the quarry sides and it is very difficult to connect beds seen in the different faces. Fortunately, however, Sibly, by marking accurately the extent of the quarry in 1912 and describing the strata then visible, has given a record of beds now concealed.

For descriptive purposes it is convenient to deal with each face separately, starting from the tunnel entrance in the centre of the south face, and later attempting to connect the strata observed.

(*a*) *Tunnel—south-west Corner.*—For about 100 yards west of the tunnel the quarry face trends in a north-west direction, after which distance it changes and runs east-west as far as the corner. These first hundred yards are much overgrown and structure is obscured, but Sibly records vertical S beds at the tunnel mouth. whilst H. H. Winwood[2] noted that at a short distance north of the tunnel the limestone dips west and finally east. These observations show that here the strata are much disturbed, owing in part no doubt to the proximity of the South Boundary Fault. At the point where the face trends east–west are seen china-stones with *Productus* cf. *cora* and *Lithostrotion martini* dipping at 80° N. This dip continues until close to the south-west corner where the same beds are observed to be much shattered. In the recessed part of the quarry, close to the corner, the limestone has been quarried back until black shales have been exposed. These shales are part of the Quartzite-shale mass forming the ridge, and at this point quarrying has intersected the South Boundary Fault, which lies slightly north of the position assigned to it in 1912. Owing to long disuse of this part of the quarry much slipping of the shales has taken place and it is impossible to determine the inclination of the fault plane.

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[1] T. F. Sibly, loc. cit. *supra*.

[2] H. H. Winwood, *Proc. Bath Nat. Hist. Soc. and Antiq. Field Club*, pt. i, 1890, 48–9.

(*b*) *Western Face.*—As the quarry face turns northwards from the south-west corner the fault is left and limestones again occupy the section. These beds are highly inclined, being vertical in their (stratigraphically) higher part, though this dip decreases to 70° S.E. lower down. The strata consist mainly of china-stones of S_2-age overlying beds varying from fine-grained, black to grey, foraminiferal and crinoidal limestones, including one band of black carbonaceous shales which was once tried for fuel. The weathered upper surfaces of these (stratigraphically) lower beds have yielded the following fossils :—*Productus giganteus* Martin, *Caninia* cf. *juddi* Thomson, *Productus hemisphericus* Sow., *Lithostrotion martini* E. and H., *Carcinophyllum vaughani* Salèe., *Bellerophon* spp.

This assemblage points to a probable low D_1 age for the beds, thus showing the inversion of the strata at this locality.

Only a small thickness of D_1 is seen, for the limestones are soon faulted out against a prominent mass of pink-purple quartzite and shales which forms a buttress jutting out into the quarry (see Fig. 1). The dip and strike of this quartzite mass is the same as that of the D-limestones, namely 70° S.E., but it is not known whether the quartzite-shale sequence is inverted or not. The following succession is that observed in the quarry ; the beds being taken in descending order :—

	Fault.	Ft.
Shales.	Papery, laminated, and broken. Colour variable purplish-dull red, though locally bleached greenish-white	9
Sandstone.	Gritty, containing quartz pebbles. Also contains black specks (? plant remains)	1
Sandstone.	Buff yellow, friable, weathering down in lower part to form whitish sand	3
Quartzite.	Very fine-grained, pinkish-white. Locally with development of thin shales having a porcellanous appearance	10
	Slight gap.	
Quartzite.	Pink-purple. (Typical "Millstone Grit") . .	4½
Shales.	Reddish . . . . seen.	3

North of this quartzite-shale mass, and separated from it by a fault is another small area of limestones, including a band of carbonaceous shales, the whole dipping 80° S.E. (These beds are recessed behind the buttress in Fig. 2.) The beds are much shattered and I have so far been unable to find any fossil evidence to fix their age; but the lithology very closely agrees with that of the D_1 strata south of the quartzite-shale mass, and it is therefore probable that this shattered mass of limestone belongs to the same zone.

On the north these limestones are thrust against a series of greenish grey-black shales, probably of Coal Measure age, which occupy the remainder of the section as far as the north-west corner of the quarry. The shale slope, forming the face, dips at about 45° E.–E.S.E. and is in fact the sole of a great thrust fault which is clearly Sibly's "West Boundary Fault", and whose actual position does not differ to any great extent from that shown on his map. The trend of the fault is arcuate, curving towards the north-west corner of the quarry, where D limestones are seen thrust against the shales (Fig. 2).

(*c*) *Northern Face.*—Lying against the West Boundary Fault and extending eastwards along the north face of the quarry are

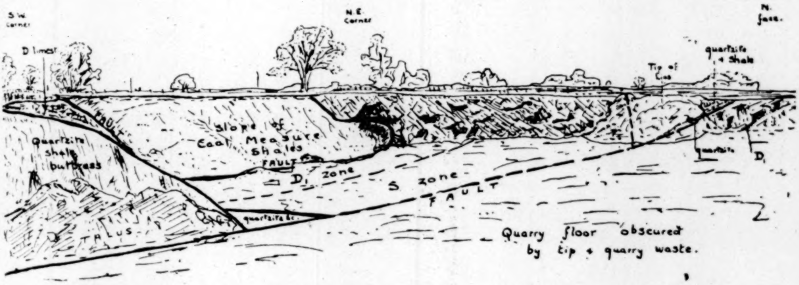
S.W. Corner
N.E. Corner
N. face.
D limest.
quartzite + Shale
Tip of Lias
Quartzite shale buttress
Slope of Coal Measure Shales
FAULT
FAULT
D_1 zone
S zone
FAULT
quartzite
D_1
quartzite bc.
TALUS
Quarry floor obscured by tip + quarry waste.

FIG. 2.—Sketch of west and north faces of Vobster Quarry. (Drawn from photographs.)

D and S limestones. The sequence is inverted and dips at angles varying from 30°–40° E.–E.S.E. The D beds, of which only a small thickness is seen, consist of massive foraminiferal and coarsely oolitic limestones. The S beds are less massive and more regularly bedded and are mainly of the china-stone type. Pseudobreccias and algal structure are locally developed.

These beds extend for about 150 yards along the northern face, but beyond this for about 20 yards the rock face is concealed by a large overgrown tip-heap of Lias. On the eastern side of this debris the limestone is once more exposed but here it is seen to dip at 20° N.W. Near the top of the section at the eastern margin of the tip are seen purplish shales and quartzite resting upon, and dipping in the same direction as the underlying limestone. This quartzite is also exposed in situ in a small scraping near the centre of the tip which thus marks the position of an infaulted block of the quartzite-shale group (Fig. 2). The north-westerly dipping limestones are mainly S_2 china-stones, though the more massive beds underneath the quartzite-shale group may represent D_1. The only fossil so far obtained from these limestones was a specimen of *Campophyllum*.

The remaining S beds extend to the north-east corner of the quarry, the dip increasing to 50° N.W., whilst near the corner signs of disturbance are evident. From top to bottom of the face the beds are flexed and show slight inversion at the base, accompanied by downward thrusting in a north-westerly direction (Fig. 3, sect. i).

In 1912 the north face was in active work and Sibly considered that with further quarrying the northern limit of the limestone would soon be reached. The presence of Tinkers Lane has checked any northward extension of the quarry, which still shows limestone in the face. The boundary must lie to the north of this lane and it is doubtful, owing to the covering of Lias, whether the position of this boundary (a fault) will ever be known with accuracy.

(*d*) *Eastern Face.*—A short distance south of the north-east corner a large unquarried buttress projects into the quarry. This is much overgrown and further obscured by Lias tippings; but from slips and scrapes on the northern side it is seen to consist mainly of pale grey and purplish shales with occasional fragments of pink quartzite. Certain deeply ironstained calcareous nodules occur and associated with these I have found several specimens of Goniatites, which were the only fossils obtained. These have been kindly examined by Mr. W. S. Bisat, who identifies them as *Gastrioceras cancellatum*, thus showing a Lower G horizon (Halifaxian), and placing the strata on the same horizon as the Haslingden Flags of Lancashire.

Neither the succession nor the disposition of the beds in this shale mass can be ascertained; though along the southern margin the present quarrying of the adjacent limestone has exposed small areas of shales. In one exposure the shales were sandy and olive-green in colour, in another (more easterly situate) black shales with irregular reddish layers were seen. These beds appeared to have a high dip to the south-west, but it is improbable that such a dip is general since the strata are close to a large fault.

South of this fault the present working face of the quarry is being extended eastwards. The face displays almost a strike section of S beds, which, except in the immediate neighbourhood of the fault, have a low dip of 30° E.–E.S.E., which is maintained almost as far as the south-east corner. At this point a slightly faulted anticline, the axis of which runs N.W.–S.E., causes the dip to swing to 35° S. The rock is mainly a dark, fine-grained limestone, the freshly quarried faces of which have so far yielded few fossils except *Seminula*.

(*e*) *South-east Corner—Tunnel.*—Along the southern face the strata dip at 35° S. Near the corner the rock is similar to that seen in the eastern face; but towards the tunnel it is lighter in colour and oolitic. In the immediate neighbourhood of the tunnel the face is completely overgrown.

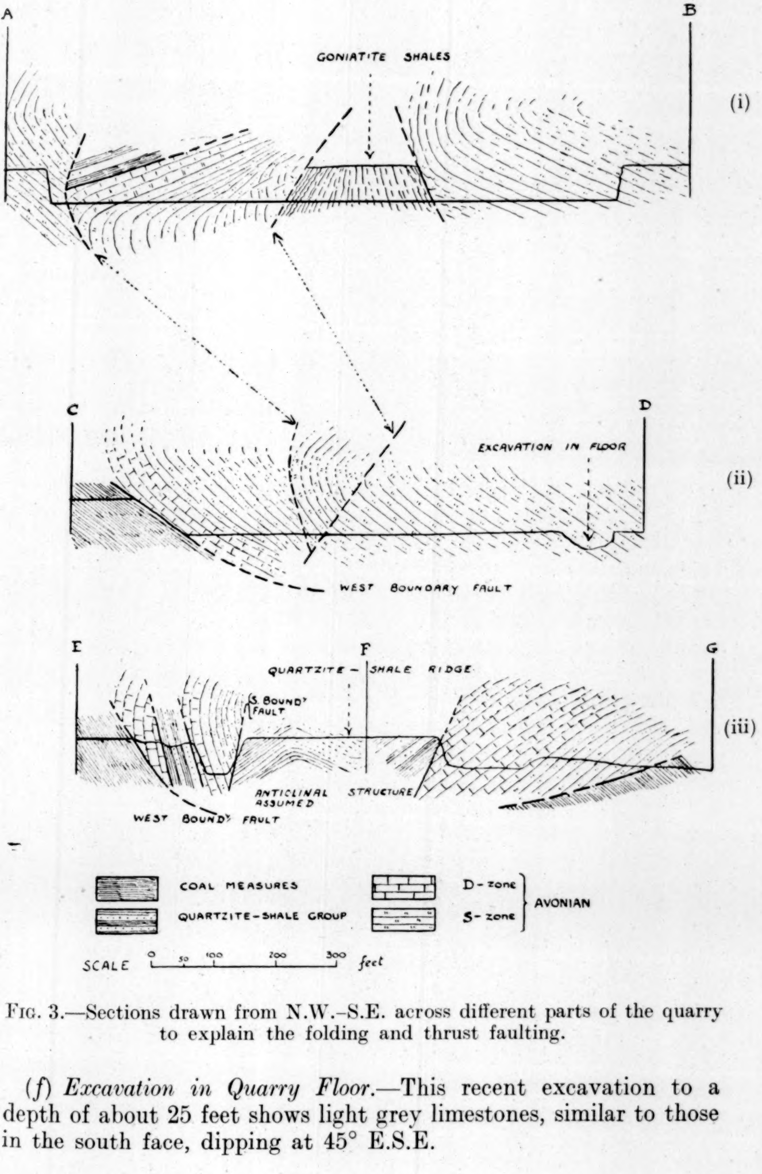
A
B
GONIATITE SHALES
(i)
C
D
EXCAVATION IN FLOOR
(ii)
WEST BOUNDARY FAULT
E
F
G
QUARTZITE – SHALE RIDGE
S. BOUND' FAULT
(iii)
ANTICLINAL STRUCTURE ASSUMED
WEST BOUND' FAULT
COAL MEASURES
QUARTZITE-SHALE GROUP
D-zone
S-zone
AVONIAN
SCALE
0
50
100
200
300
feet

FIG. 3.—Sections drawn from N.W.–S.E. across different parts of the quarry to explain the folding and thrust faulting.

(*f*) *Excavation in Quarry Floor.*—This recent excavation to a depth of about 25 feet shows light grey limestones, similar to those in the south face, dipping at 45° E.S.E.

II. CONSIDERATIONS OF THE FAULTING.

From the detailed description of the quarry it is evident that the faulting is far more complex than was hitherto suspected, and for this reason and the previously mentioned concealment of strata over the quarry floor it is extremely difficult to connect the strata seen in the different faces.

At the western end of the quarry the D beds resting against the West Boundary Fault at the north-west corner are shown on the map (Fig. 1) to extend southwards and to join with beds, presumed to be of the same age at the southern end of the same fault. Sibly's photograph (pl. iii, fig. 2),[1] taken in 1912 of the western face, which then lay some 50 yards to the east of the preasent fce, shows an unbroken sequence of S_2 beds. Quarrying back this zone must have been passed through and D_1 encountered. Since then the strata have been completely removed as far as the Boundary fault, except at the north and south ends. From this evidence the block of S and D beds east of this fault is considered to be unbroken.

The connection of the quartzite-shale masses in the north and west faces presents greater difficulties. Although no trace of such masses was observed in the 1912 quarry face it does not imply that such connection is unwarranted. Being of no commercial value such rock would remain unquarried, and it therefore seems highly probable that neither of these quartzite-shale masses ever extended into the quarry much further than they do at the present. The convergence of the two sets of faults which bound these beds would pinch out the strata before they reached the 1912 face. The faulting should, however, have been noticeable in this face. Sibly certainly draws attention to the shattered nature of the beds in the south-west corner, which could easily have been caused by this faulting, but his photograph of the northern face (pl. iv, fig. 1)[2] shows that the strata appear to be unbroken. The faulting may, however, have been parallel to the bedding planes, thus causing little or no dislocation. Such absence of dislocation is very noticeable throughout the quarry at the thrust junctions of D_1 and the Quartzite-shale group.

The contrary direction of the dips of the Quartzite-shale group in the north and south parts of the quarry can be explained by an isoclinal fold pitching north-east (Fig. 3, sects. ii–iii) in the same way as that described by the author in the Emborough Quarries.[3]

The same explanation is offered to account for the dips in the limestone block east of the Quartzite-shale segment.

The shale mass containing Goniatites is also considered to be a wedge-shaped mass between two faults. Sibly[1] remarks (p. 63) that near the eastern end of the north face the limestone is replaced by masses of coarsely crystalline calcite and cut by irregularly slickensided joints. Such shattering is no doubt due to the proximity of the faults bounding the shale mass.

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[1] T. F. Sibly, loc. cit., *supra.*

[2] Idem.

[3] F. B. A. Welch, "The Geological Structure of the Central Mendips": *Q.J.G.S.*, lxxxv, 1929, 60.

One feature very noticeable in this and Vobster Old Quarry is the marked absence of dislocation at the thrust junctions of the Quartzite-shale masses and the D limestones. In the main Mendip area soft shale beds occur low down in D_1 and it may have been along this unresistant band that the thrusting took place, the shales acting as a " lubricant " to the thrust masses and thus no serious shattering took place either above or below the thrust planes.

A general inspection of the structure of the inlier shows a series of narrow infaulted segments of pitching isoclinal folds (Fig. 3, sects. i, ii, iii). The faults, except for the West Boundary Fault and the thrust south of Vobster Old Quarry bordering the inlier, appear to be high-angle thrusts converging towards the south-west. The relationship of the inlier to the main Mendip folding will be treated in a communication dealing with the tectonics of the Eastern Mendips.

NOTE ON THICKNESS OF S BEDS.

T. F. Sibly (p. 66), in summarizing the extent of the zones seen in Vobster Quarry, stated that there was no palaeontological evidence for S_1, and recent investigations support this view, though it must be admitted in the eastern part of the quarry fossils are extremely rare. The conclusion reached in 1912 was that 520 feet of S_2 were developed, the quarry apparently showing an unbroken sequence. If the present interpretation of the tectonics is correct, this sequence of S beds is traversed by one if not two faults.

With the complexity of the faulting now revealed, and the probability of more being exposed by further quarrying, it would seem unsafe to assign any value to the thickness of zones developed.

THE AGE OF THE QUARTZITE SHALE MASSES.

Since no fossils have been found in the quartzite-shale masses seen in the north and west faces and forming the ridge separating the two quarries no definite horizon can be assigned to these beds.

Compared on purely lithological grounds, however, with strata in the main Mendip area, they probably represent an horizon about 100 feet above the uppermost D_2 limestone (the top of D_2 has been taken immediately below a gritty limestone series crowded with *Buxtonia scabricula* (Martin), which is succeeded by quartzites of " Millstone Grit " type), and lower than that represented by the Goniatite shales.

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[1] T. F. Sibly, loc. cit., *supra*.

FURTHER EXPOSURES OF LIMESTONE IN THE AREA.

East of the Vobster Quarries are the excavations at Bilboa. In 1912 Bilboa Quarry was abandoned and drowned, thus rendering examination impossible. Recently, however, this has been drained and quarried on a large scale, whilst a second quarry, further east, was being opened when the locality was last visited.

In the main (westernmost) quarry the strata have a low dip approximately 10°–15° in a S.E. direction and show a slight anticlinal arrangement, the axis pitching S.E. The lowest beds, which are seen in the northern part of the quarry, consist of compact, grey crystalline and sparsely oolitic limestone, which, so far, has not yielded any fossils. Succeeding these beds is a thin reddish parting of shale from which I obtained *Carcinophyllum vaughani* Salèe. (early form), *Carcinophyllum* cf. *parkinsoni* Ryder, *Palaeosmilia murchisoni,* E. & H. (specialized form).

A few feet above this shaley parting was a band with *Bellerophon* spp. (cf. S.W. corner Vobster Quarry), and at a slightly higher level, seen in the eastern face, reddish foraminiferal limestone from which I obtained *Chonetes papilionacea* and one specimen of *Amplexus* sp. The faunal assemblage of the beds down to and including the shale band points to a low D_1 age for the strata.

A short distance to the east of the quarry a second excavation has recently been started. When last visited the Lias covering had been removed from a rectangular area revealing the smooth top of the limestone. This had been broken into at one corner; but it was not possible to obtain any fossils or to record any dip. The rock was a pinkish crystalline limestone, much stringed with calcite and evidently showing signs of shattering. It is probable that this limestone is close to the easterly prolongation of the thrust fault which separates the whole of the Vobster Inlier from the Coal Measures on the south.

Provided the inversion of S and D beds, seen in Vobster Old Quarry, is maintained eastwards, the Bilboa limestones will probably represent the normal sequence of S and D of the southern limb of a northwardly folded isocline.

REVIEWS.

Die Oszillationstheorie. By Erich Haarmann. xii + 260 pp., with one plate and 78 text-figures. Stuttgart: Ferdinand Enke, 1930.

NO geologist doubts that there have been vertical movements of the earth's crust, but in theoretical discussions their magnitude and extent are often ignored. Faults with a vertical throw of ten or fifteen thousand feet are known even in regions where the strata still remain nearly horizontal, and there are widespread accumulations of sediment which require even greater depression of the crust. But spectacular overthrusts and recumbent folds have diverted attention from the more modest but equally deserving normal faults, and the importance of vertical movement has been greatly underrated.

For Professor Haarmann, however, the primary crustal movements are vertical, and all others are secondary consequences. This was the view of Suess, it is still the view held by Gregory, and there is as much to be said for it as for any other general theory. But the vertical movements imagined by Haarmann are very different, both in kind and in cause, from those conceived by Suess and Gregory. Haarmann rejects the contraction and other theories, and thinks it most probable that vertical movement is an attempt to restore an equilibrium which has been disturbed by wandering of the pole. He quotes Lambert as saying that the displacement of a continental mass of the size of Europe through 45° of latitude would alter the position of the pole only about half a degree; and he concludes, conversely, that an alteration of half a degree in the position of the pole would produce a change equivalent to that of moving Europe through 45°. Unintentionally, no doubt, there is a kind of suggestion that this is a comparatively easy method. The real implication is that to alter the position of the pole even to that extent requires a very great force; and here the author freely admits that he passes beyond the present limits of our knowledge. He does not know how the displacement of the pole is brought about, but thinks that it must be due to cosmical causes, and this view is supported by the periodic nature of earth movements.

It is an essential part of the theory that the sial is not rigid. In some circumstances, indeed, it is more mobile than the sima. Accordingly, in response to a change in the position of the pole the layer of sial may thicken in some regions, and thin in others, in such fashion as to restore the disturbed equilibrium. Where it thickens there is elevation, where it thins there is depression.

This is the fundamental idea of the theory. Mountain-building